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MAY 1951

THREE-QUARTERS PEACE

ADDRESS BY VICE-ADMIRAL A. G. NOBLE, U.S.N.

CHIEF OF NAVAL MATERIAL

BEFORE

AMERICAN SOCIETY OF NAVAL ENGINEERS BANQUET

STATLER HOTEL, WASHINGTON, D. C.

27 APRIL 1951

THREE-QUARTERS PEACE

In any analysis of our present situation, we must realize that, strictly speaking, we are not now engaged in *serious* warfare. On the other hand, we are hardly living in an atmosphere of peace and harmony throughout the world. We are in a state of unrest, more properly described in economic terms as "three-quarters peace." Bluntly put, we find ourselves in this situation largely because we suffered ourselves to become militarily weak. In order to understand the full import of this present situation, we must review the progressive steps which led up to it—steps which led us from the state of a wishful-thinking peace in 1945 to a state now threateningly close to world war.

The reduction of our military might through rapid demobilization, after V-J Day, was an important factor contributing to our present predicament. This radical reduction of our military forces resulted not only in a weakening of our national security but also it considerably lessened our world prestige. This reduction in our military strength undoubtedly was interpreted as a weakness in National Policy, and the armed conflict which has followed was intended to test our reactions. Furthermore, in hastening demobilization, we were forced to abandon much of the material of our physical might—and, in several instances to do this in theaters where it has fallen into the hands of hostile forces who are now using it against us.

We had the urge of impatience, back there in 1945 and 1946, and we were intolerant of military control. These factors resulted in reducing the role of the military in government, and also, in reducing the influence of the military in the field of foreign policy, even reducing military influence in determining our own policy in national security and defense matters.

Further, as contributing to our weakened condition, we lacked—or abandoned—a firm policy on the strength of our military forces needed for national defense and security. This indecision undoubtedly resulted from a *failure* to interpret correctly the tenor of the times, and a *failure* to recognize the seriousness of the threat of the communist forces which have been opposing us in all areas where the United States has an interest.

The extreme sensitivity of Military planning to the day by day political climate has resulted in an uneconomical *stop and go* program.

Recognizing the evil intentions of those who oppose our interests, it may prove to have been fortunate that the Korean situation broke upon us not only with suddenness, but also at a time when great effort was being placed upon further reduction of our Armed Forces. It is ironic that the Korean crisis revealed that the Communists did not appreciate the drift of our policy and its weakening

influence upon our national security. In fact, had we been left to our own devices, we might have lost the ability to react promptly against aggression.

The action in Korea has brought with it an awakened concern over both our Asiatic relations and our world-wide relations. There has been brought home to us, and particularly to our leaders, the cold realization that what has happened in Korea *can* happen in other places. Satellite armed forces can be used against other free nations and, in such strength as not only to warrant, but actually to require the rallying assistance of *all* free nations.

I cite, as a warning to aggressor nations, the recent and vitally important action of the Senate in agreeing to the stationing of Army Divisions in Europe, and hence an extension of our armed strength in support of the free nations of Europe.

The importance of this action should not go unheeded. The Evening Star of April 5th pointed out very cogently, and I quote:

"The thing that really counts, the thing that history will record as one of the most significant developments of our generation, is that the Senate has given its approval to the stationing in Europe, in peacetime, of a total of six divisions of American troops as a garrison force. The Senate has done this in explicit recognition of the fact that 'the threat to the security of the United States and to our North Atlantic treaty partners' makes it necessary to station United States armed units abroad so as to 'contribute our fair share of the forces needed for the joint defense of the North Atlantic area'."

The Senate, in approving this assignment of a portion of our military strength to Western Europe, gives clear proof that the United States is fully and firmly committed to fight on land, on the sea and in the air, if and when Western Europe should ever be attacked. There is no equivocation, here, in regard to our national interest.

What is of greater moment, not only actually, but also psychologically, is our unwavering intention to preserve national security, and our fixed determination to render full assistance wherever needed to oppose aggression or to protect free nations from hostile action.

We can readily see the manpower implications in the progressive steps which have been taken to prevent the spread of communism. For example, in 1948, when the government of Czechoslovakia was overrun, we temporarily stopped further curtailments in our military strength, and more than that, Congress revived in a time of peace the Selective Service Act. When the Korean situation broke, there was immediately approved a progressively increased strength for the armed forces—to their present authorized strength of 3½ million men. And now, to further augment these actions and to provide military strength adequate to support our commit-

ments, the Universal Military Training Bill—in a reduced form, it is true—will probably be passed by the Congress.

Furthermore, we have recognized the realities of the present situation not only through action taken to increase our armed forces, but similarly through the dispatch of additional forces—land, sea and air—to the Asiatic Theater. Also, we have taken steps to implement the North Atlantic Treaty Organization and to lift materially our level of preparedness. All of these actions will have a profound influence upon the state, the strength, and the readiness of our nation.

This increased defense effort in all fields, coming when our national production is at its height and when employment has reached an unparalleled level, is placing demands upon us which can be met only by a strong economy capable of producing the munitions of war needed to back up our global commitments. These demands have resulted in some curtailment of production for civilian goods, and it is reasonable to expect that there will be additional curtailment.

It is frequently said that we are traversing the same steps now that we traversed in 1940 when we were preparing for what became World War II. To a limited degree this is correct. It is true that it appears as though the whole horrible apparatus of a war economy is being reassembled, with our political leaders and our economists looking for the bits and pieces that should be culled out and used again. This attitude is reasonable and natural. The economic impact of the present creeping mobilization is essentially the same as that of a fighting war. In both, the economic problem is to shift our resources—men, machines and materials—away from work on civilian goods and into the production of munitions of war.

There are, however, two fundamental differences between the economics of war and the present economics of defense. They are differences in scope and in timing. For war, the required effort is large-scaled but relatively brief. For defense in a cold war, it is less intensive but more prolonged. So much emphasis has rightly to be put on the need to make willing sacrifices for defense that it is easy to forget how big is the difference in size between what is being attempted now and what was done ten years ago.

The essence of the war economy of 1939-45 was that a moderate inflation was used to lubricate the initial shift of resources to military purposes. In this instance inflation was prevented from getting out of hand. Resources were removed from the purchasing power of inflated private incomes by a variety of physical and moral compulsions—on the consumer in the form of rationing, on the worker in terms of allocation and direction of labor, and on the business man by virtue of price controls and direct production controls. A certain amount of inflation can be accepted in wartime, provided it is limited in scope and in duration. But to transfer this

economic policy to the situation of a "three-quarters peace" could be disastrous.

For one thing, a persistent fall in the value of money, continuing over a decade or more, would have disastrous consequences on the structure of society, on fixed assets and fixed incomes—in short on the flexibility and efficiency of our whole economy.

The current program for rearmament does not envisage the tremendous build-up in volume which was stimulated by our entry into World War II. Rather, it envisages a normal build-up to a plateau level sufficient to meet the early phases of mobilization. Once this is attained, the level of production for military items may be reduced, at the same time maintaining production lines for important items at minimum level, in order to have available adequate facilities and experienced personnel. This latter situation may be expected to be maintained over a period of several years—five, ten, perhaps even twenty.

Based upon this premise, there is optimism with respect to the production capabilities of the United States. Mr. Wilson has reported that "One year from now, with unflagging determination and effort, we will achieve a formidable strength in many phases of modern warfare. Two years from now we should have military and economic strength sufficient to give us reasonable safety against aggression". And finally, he believes, it is possible by early 1953 that some or all of our controls can be taken off and that more effort can be devoted to production for civilian needs.

It is generally agreed that the success of our production effort depends on our winning the battle of inflation. The winning of this battle calls for the subordination of selfish ends to the common welfare, and to do this in a measure beyond what is commonly demanded in any period short of actual war. It calls for a fair presentation of the claims of every segment of society, an open and willing participation by all concerned, and a readiness to abide by decisions which are arrived at through fair and honest means. It calls for every organized group to consider the just demands not only of other organized groups, but of the unorganized groups as well—the consumer, old John Q. Public—the public as a whole.

It is imperative, in this critical time of "three-quarters peace", that inflation be brought under control and maintained under control. Inflation feeds upon itself; and unless determined and successful efforts are provided for its control, it, rather than the enemy, will be the cause of our defeat. For example, the destroyer costs today approximately four times what it cost in World War II. As a result of inflationary trends, a 50 billion dollar military program will not buy today as much as a 25 billion dollar program did in 1944. In fact, as some one has graphically put it, inflation is charged with shooting down 10% of the aircraft which the money made available a few months ago was intended to procure.

Controls can always, of course, be *made* to work—at a cost, and with some measure of success. But the costs—in bureaucratic interference, as well as in money and manpower—may be high. If controls work badly, they will bring political discredit on the Government—as much discredit as would flow from the alternative policy of letting the inflation go unsuppressed, or from the policy of a course of retrenchment—long considered "politically inexpedient" —which would cut inflation at the source.

The extent to which we are willing to go in prescribing controls (which means rationing) and the extent to which we are willing to realize that the administration of controls is necessary to defeat inflation, will to a large degree determine the measure of our success in combatting inflation. However, we should appreciate that there are no precedents for the situation with which we now have to deal. Certainly, the control provisions which were used in World War II will not prove adequate during a "three-quarters peace".

In the absence of a national police force, the only means by which controls will function effectively will be through the imposition, by each person upon himself, of self restraint and self discipline. In our normal free atmosphere I fear that this will be a most difficult task. In this coming situation we will have to *welcome* the opportunity to share equally in sacrifice. The degree to which all are willing voluntarily to participate in that experience will tell the story.

There is one outstanding quality of our people, and that is their reaction in emergencies. Within the space of my lifetime I have witnessed, and to a degree participated in, the supreme efforts of both World War I and World War II. Both of those efforts were recognized and analyzed at the time as being Herculean. They were. The response to our next major emergency, into which we have now already entered, can be nothing more—nor less—than the same type of effort.

It has been characteristic of us as a nation to discuss our problems, to analyze them, and then even to decide that they are impossible of solution. The miracle of our people is that, having decided that a task is impossible, they have turned to and performed it.

The degree to which we voluntarily unite in the battle of inflation will mark the degree of our success in winning the battle of "three-quarters peace".

On the basis of our historical accomplishments, in the knowledge of the tenor of the times, and with faith in the determination of our people, I am confident that the present situation will not find us wanting.

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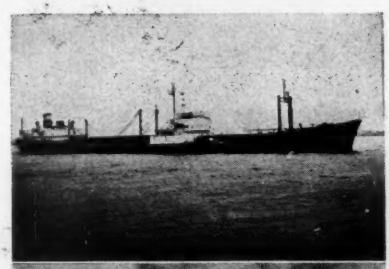

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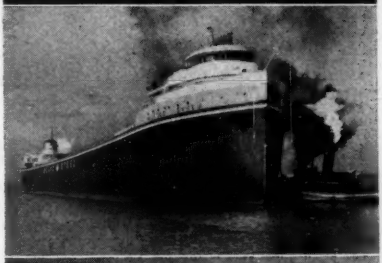

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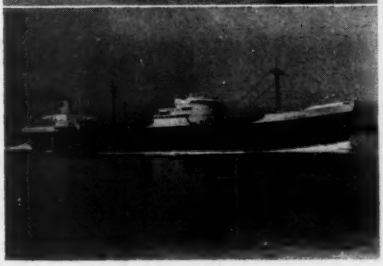

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The Wanderer, leased from the U. S. Navy by the Sperry Gyroscope Company, Division of the Sperry Corporation, Great Neck, L. I. She is 103 ft. long with a displacement of 175 tons.

Still sound and able after 19 years of constant service under two owners... that is the record of Sperry Gyroscope's marine electronics laboratory vessel, *The Wanderer*. She's a proud example of sound, pioneering design, sound construction . . . and ample use of Monel® to prevent trouble where metal troubles usually start.

The Wanderer was built in 1930-31 by J. F. James & Sons in Essex, Mass. Her first owner, R. W. Allen, wanted a motor yacht for very long cruises, one capable of going almost anywhere in any weather. For this service, a staunch, seaworthy hull was a necessity.

The Wanderer's designers decided upon an adaptation of the "Maierform" type of deep-sea fisherman hull. The choice was a wise one, for she rides clean and dry in the severest weather and has kept at sea through hurricanes and in long tours of wartime service.

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***The Wanderer's* Monel propeller shaft, 6½" dia. by 14 ft., was machined by the Hyde Windlass Co., Bath, Me. Her buoyant rudder, (like her fuel and water tanks) was fabricated from Monel sheet by the Liberty Coppersmithing Co., Philadelphia, Pa.**

In 1950, *The Wanderer* was drydocked at Jakobsen's Shipyard, Oyster Bay, L. I., for overhaul. Here's what an inspection showed about her Monel equipment:

1. *Her 6½ inch dia. Monel shaft, after 19 years of service, showed an almost unbelievably small amount of wear—only 0.037 in., on the radius.*
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3. *Monel galley tables, sinks, smoke hood, and stove exhaust pipe were in fine condition. The tables, sink, and trim shone like polished silver.*
4. *There has been no sign of trouble or contamination in fuel or water from her Monel tanks.*

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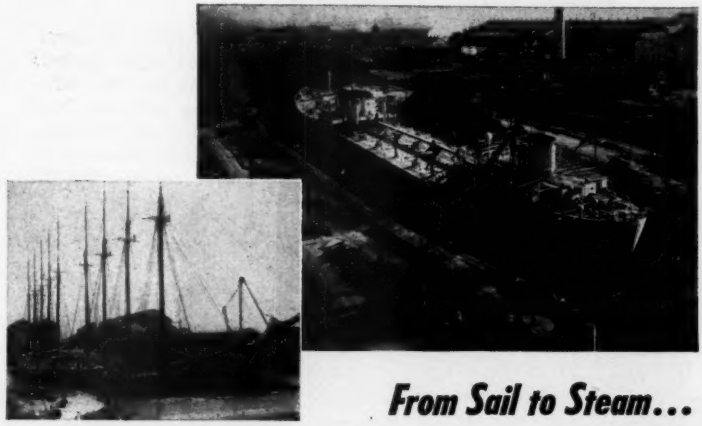

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At the turn of the century facilities at Newport News included an 800-foot dry dock to accommodate the world's largest ships of that time. Development and expansion of facilities in the plant have kept pace with world maritime progress. Today Newport News has unexcelled equipment within the 225-acre plant for the complete on-the-spot execution of all types of shipbuilding, ship repair, and conversion work.

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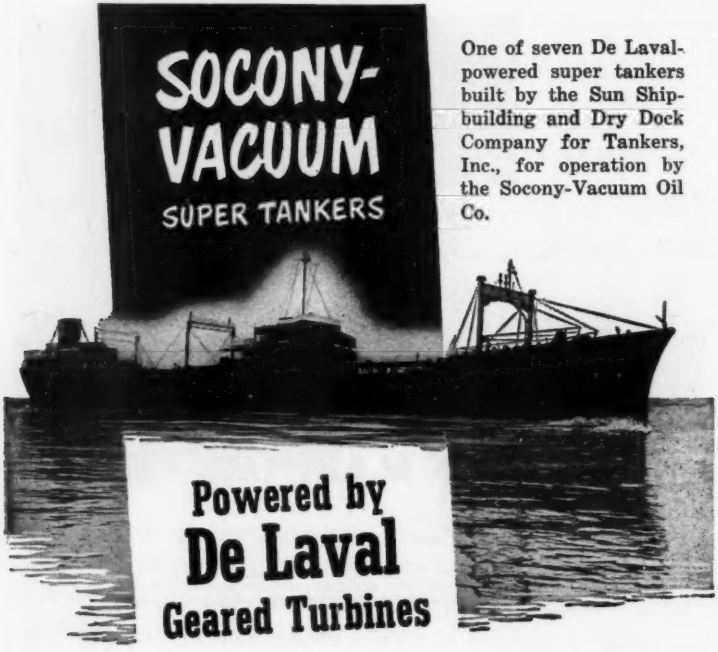

One of seven De Laval-powered super tankers built by the Sun Shipbuilding and Dry Dock Company for Tankers, Inc., for operation by the Socony-Vacuum Oil Co.

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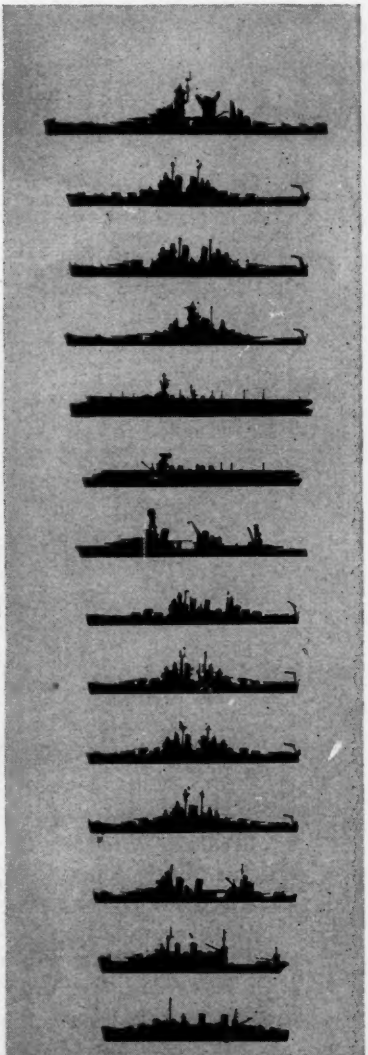

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FB-651

Specification Chemicals for the Government and its Contractors

STANDARD RUST PROOFING PRACTICE THE WORLD AROUND
CHEMICALS ACP PROCESSES

PHOSPHATIZING, RUST PROOFING AND PAINT BONDING CHEMICALS

Specification Number	ACP Specification Chemical
QQ-P-416	"Lithoform," "Zinodine"
RR-C-82	"Lithoform" No. 32
MIL-C-5541 (See also QPL-5541-1)	"Alodine"
MIL-S-5002	"Alodine," "Granodine"
JAN-C-490, Grade I	"Granodine"
JAN-F-495	"Granodine," "Lithoform"
JAN-L-548	"Permadine"
AN-E-19	"Alodine," "Zinodine"
AN-F-20	"Alodine," "Granodine," "Lithoform," "Permadine," "Thermoil-Granodine," "Zinodine" (See also U. S. A. 3-213)
U. S. A. 57-0-2	
Type II, Class A	"Thermoil-Granodine"
Type II, Class B	"Permadine"
Type II, Class C	"Granodine"
U. S. A. 51-70-1	
Finish 22.02, Class A	"Thermoil-Granodine"
Finish 22.02, Class B	"Permadine"
Finish 22.02, Class C	"Granodine"
U. S. A. 50-60-1	"Granodine"
U. S. Navord O.S. 675	"Alodine"
U. S. N. Appendix 6	"Lithoform"
Navy Aeronautical M-364	"Permadine," "Thermoil-Granodine"
16E4 (Ships)	"Alodine," "Granodine," "Zinodine"
AN-C-170	(See MIL-C-5541)
U. S. A. 72-53	(See AN-F-20)
AXS-1245	(See JAN-C-490)

RUST REMOVING AND METAL CONDITIONING CHEMICALS

Specification Number	ACP Specification Chemical
JAN-C-490, Grade II	
Type 4	"Deoxidine" Nos. 126, 512, 526, 624, 670
Type 5	"Deoxidine" Nos. 170, 171, 670
MIL-C-10578	
Type I	"Deoxidine" (Wash-off)
Type II	"Deoxidine" (Wipe-off)
U. S. A. 98-20007	"Deoxidine" No. 424
U. S. N. Appendix 6	"Deoxidine"
U. S. A. 3-213	(See MIL-C-10578)

METAL CLEANING CHEMICALS

Specification Number	ACP Specification Chemical
JAN-C-490 Grade II	
Type 2	"Ridoline"
Type 6	"Ridosol"
U. S. A. 3-192	"Ridoline" No. 3192

ACID INHIBITORS, PICKLING

Specification Number	ACP Specification Chemical
U. S. N. 51-I-2	"Rodine"

Additional copies of this chart and descriptive folders on ACP Specification Chemicals listed above are available on request.

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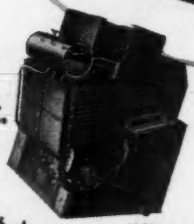

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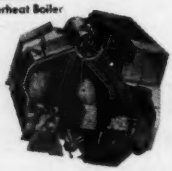

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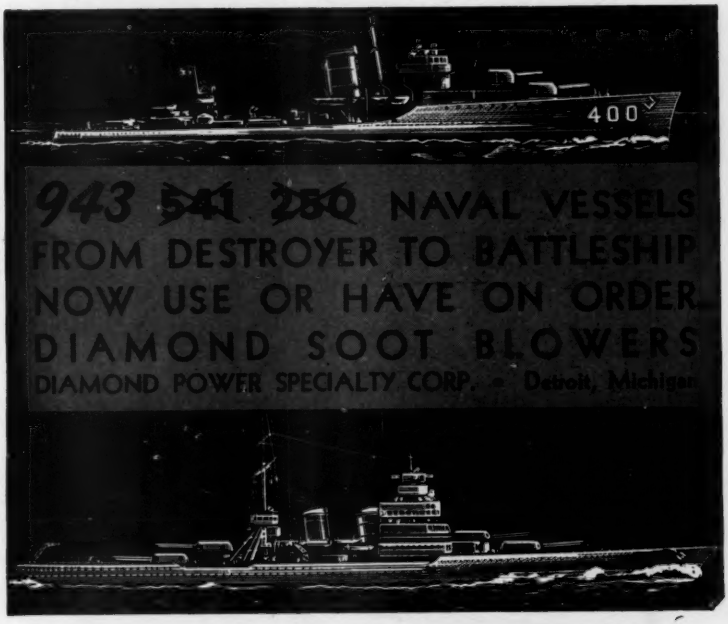
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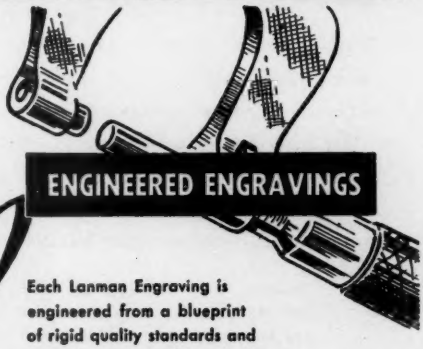

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S. S. *Independence*

Rear Admiral Louis Dreller, U. S. Navy,
President of the Society for the remainder of 1951.

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JOURNAL

OF

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

VOL. 63. MAY 1951. No. 2

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SECRETARY'S NOTES

OFFICERS OF THE SOCIETY

Official orders have removed several of the essential candidates of last year's election from the Washington scene. The Council has selected successors to those detached.

Rear Admiral David H. Clark, U.S. Navy, completed his term as Chief of the Bureau of Ships on February 1. It had been expected that he would remain in Washington but instead he was ordered to command the Norfolk Naval Ship Yard. Upon receipt of Admiral Clark's resignation as President of the Society, the Council took no action immediately. It has now accepted the resignation effective on April 28 and has selected Rear Admiral Louis Dreller, U.S. Navy, to serve out the remainder of the 1951 term. Admiral Dreller, a Naval Engineer of wide experience and well known attainments, is at present on duty in the Office of the Chief of Naval Material.

Captain Charles M. Tooke, U.S. Navy, whose term as a member of the Council was due to expire on December 31, 1951, was detached from the Bureau of Ships and ordered to duty as Production Officer of the newly reopened Naval Shipyard at Long Beach, Calif. Captain Rawson Bennett, U.S. Navy, was chosen by the Council to complete Captain Tooke's term of office.

Inasmuch as Admiral Dreller was a member of the Council at the time of his appointment to the Presidency, a vacancy was created in the Council. This was filled by selection of Captain Joseph V. Duval, U. S. Navy who will serve for the remainder of the term which expires on December 31, 1951. Captain Duval is on duty in the Bureau of Ships as Head of the Electrical Branch.

Commander C. H. Campbell, USNR, just elected for a two-year term to the Council, has been transferred from duty in the Bureau of Ships to the Boston Naval Shipyard. He will be succeeded on the Council by Captain Fred Weisner, USNR. Captain Weisner is employed in the Power Branch of the Office of Naval Research.

The complete roster of the Council as it exists at the time of going to press will be found at the head of these notes.

1951 Annual Banquet

In 1950 the annual banquet reached very nearly what was thought to be the capacity of the Washington Statler Hotel. A total of 1,286 were served. This year, on the closing date, the banquet committee had a total of 1,532 legitimate applications in hand. It was found possible to expand the capacity to take care of this unexpectedly large number. Needless to say, the added places were not well placed and a number of members and guests had anything but choice seats.

Decision to accept all applications in spite of the unsatisfactory arrangement was done advisedly by the Banquet Committee. The assignment of location was arrived at by lot as was announced in advance. It is probable that decision will have to be reached next year as to whether to repeat the same sort of thing or to limit the banquet to members only.

In spite of the unhappiness of many because of the poor location of their places, there can be no doubt that the 1951 Banquet was an outstanding success. Included among the guests were several past presidents and past secretaries of the Society, the Secretary of the Navy, the Honorable Francis P. Matthews, Assistant Secretary of Defense, the Honorable Marx Leva, two Assistant Secretaries of the Navy, the Honorable John Koehler and the Honorable John Floberg, and Admiral Forrest Sherman, Chief of Naval Operations.

The Banquet meeting was presided over by the retiring President, Rear Admiral David H. Clark, U.S. Navy. Rear Admiral D. W. Leggett, U.S. Navy, officiated as toastmaster. Rear Admiral Louis Dreller, U.S. Navy, the incoming President, was introduced.

The principal and only speaker was Vice Admiral Charles H. Noble, U.S. Navy, Chief of Naval Material. His subject, "Three Quarters Peace," presented a very intriguing picture of the current mobilization problem. For those who missed the banquet and thus were deprived of hearing Admiral Noble's address, it has been printed and is distributed with this issue of the JOURNAL.

CENTENNIAL OF ENGINEERING, 1952.

In 1852, the first engineering society in the United States, The American Society of Civil Engineers, was founded. Our own Society was not founded for 36 years.

It is planned to celebrate the Centennial of Engineering in Chicago from approximately July 1 to September 30, 1952. The Board of Directors of Centennial of Engineering, 1952, Inc., has invited the American Society of Naval Engineers to join with the five constituent societies of the Engineers Joint Council to participate. The type of participation suggested was a special meeting of the Society to be held in Chicago during the period of the celebration.

The Council fully considered this invitation but reached the decision that active participation was not feasible. However, it expressed full agreement with the purpose of the celebration and requests all members of the Society in the Chicago area to contribute in any possible way to the success of the undertaking.

International Conference of Naval Architects and Marine Engineers, 1951.

Officers and members of the Society have been invited to attend the International Conference of Naval Architects and Marine Engineers which is being held between 25th June and 6th July 1951, during the Festival of Britain. The Council has taken action to designate Captain Ralph K. James, U.S.N., Captain Robert A. Smyth, U.S.C.G., and Mr. John C. Niedermaier to represent the American Society of Naval Engineers. The two latter are members of the Council. Captain James and Mr. Niedermaier are presenting technical papers.

Copies of Journals.

The Librarian of the New York State Maritime College has requested assistance in obtaining copies of certain issues of the Journal of the American Society of Naval Engineers. The issues desired are:

1902	Volume 14	complete
1915	Volume 27	complete
1916	Volume 28	complete
1922	Volume 34	Number 3
1926	Volume 38	Number 1

If any member has any of the above numbers which he would like to present to the New York State Maritime College it is requested that they communicate directly with:

The Librarian
New York State Maritime College
State University of New York
Fort Schuyler,
New York 61,
N. Y.

PART ONE

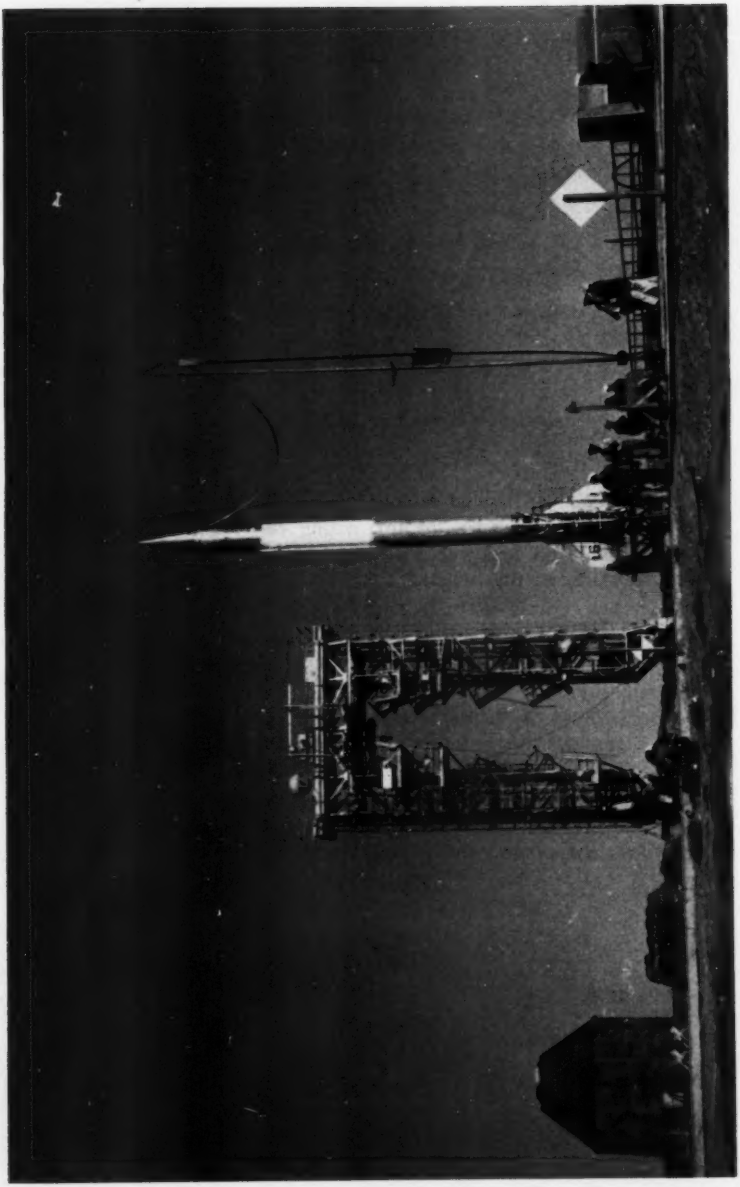
ORIGINAL ARTICLES

The articles which the Editor, acting under the supervision of the Council, has accepted for publication in Part One are the original works of the authors.

They are offered in furtherance of the Society's raison d'etre: to further the advancement of naval engineering. Discussion of any article is invited for publication in a subsequent issue.

Permission to reprint is freely granted on condition that *full acknowledgment is given* to the author and to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.

All articles which have been written by naval personnel or by civilian employes of the Navy Department and are published herein carry the personal view of the authors and, unless specifically so stated, do not express the official views of the Navy Department.



PROBING THE ATMOSPHERE WITH ROCKETS

LIEUTENANT G. R. HILL, USN

THE AUTHOR

LIEUT. HILL enlisted in the Navy at the age of 17 shortly after graduating from the State Secondary Agriculture School, Blountsville, Alabama. He attended the Navy Radio School at Naval Operating Base, Norfolk, Virginia in 1929-1930 and has been active in Naval communications and electronics ever since. He attended the Radio Material School, Bellevue, D. C., in 1940 where he was among the first group to receive technical training in radar in this country. He served in the Cruisers *Minneapolis, San Francisco* and *Canberra* during World War II. After the USS *Canberra* was torpedoed off Formosa in 1945 he attended radar courses at Massachusetts Institute of Technology and Navy schools in Boston while the ship was undergoing repairs. He has since completed a year's college credit through USAFI. Lieut. Hill is now serving on the staff of the Director, Naval Research Laboratory where he has been Program Officer for Radio Division I since 1947. The Rocket Sonde Branch which is engaged in research of the upper atmosphere is a branch of this Division (Radio Division I).

Time: 1017 A.M. (M.S.T.)
Date: 21 November 1950
Place: The desert floor at White Sands, New Mexico

A flash of flame, a s-w-h-o-o-s-h, and Viking rocket number five, lifted by 20,000 pounds of thrust, rose majestically from the launching stand on the desert at White Sands, New Mexico, and soared far up into and beyond the earth's atmosphere into outer space to an altitude of 107.5 miles for a new altitude record for American-built single-stage rockets.

Loaded with nearly seven hundred pounds of research instruments the Viking again performed its carrier mission for the Navy's Upper Atmosphere Research program. Unlike most rockets, the Viking was designed and developed for just this purpose—to act as a vehicle to carry research instruments into the upper atmosphere. The rocket is 48 feet long, 32 inches in diameter and can carry a maximum "payload" of 1500 pounds. The engine burns liquid oxygen and alcohol and will deliver a thrust of 20,000 pounds for over a minute. Empty, the rocket weighs only 2230 pounds; loaded, with fuel and research instrumentation (referred to as "payload") it weighs over 11,000 pounds.

Stabilized in pitch, roll and yaw by internal controls, the Viking is an ex-

cellent outer-space laboratory from which a study of the upper atmosphere is being made in the following fields: cosmic rays; the ionosphere; temperature, pressure and composition measurements; and astrophysics involving primarily the spectrum of the sun.

The Naval Research Laboratory has been exploring the earth's atmosphere since early 1946 with rocket-borne experiments using captured German V-2, and American-built Aerobee and Viking rockets as vehicles.

When it was first proposed to employ rockets to study the upper atmosphere, the total extent of their usefulness for the purpose was largely a matter of conjecture. The rocket's payload limitations, supersonic speeds, high acceleration, varying aspect, short flight time and self-destructive impact after flight were the unknown factors. It was believed, however, that the rocket's main advantages would far outweigh the shortcomings, and this, in fact, has been the case. During the past four years the value of the rocket as a research tool has been firmly established.

Initially the Naval Research Laboratory's Rocket Sonde program contemplated the procurement of a series of rockets for use in upper atmosphere research. Fortunately, however, an invitation was extended to the Laboratory in January 1946, to participate in the V-2 program by the Ordnance Department of the Army. The Army had captured 100 German V-2 rockets in 1945 and brought them to the Proving Grounds at White Sands. Here was set up the necessary instrumentation to conduct a firing program to gain experience in the military aspects of handling and firing rockets of this size, and to obtain information on the technical characteristics of the rockets as well as optical and radar tracking data. This was the beginning of a collaborative program (later joined by other agencies) between the Naval Research Laboratory and the Ordnance Department of the Army.

The Ordnance Department of the Army agreed to furnish and fire the V-2 rockets while the Naval Research Laboratory would coordinate the upper atmosphere research to be done in the V-2's. To facilitate this coordination, a V-2 panel was set up, composed of members of various universities and activities contemplating upper atmosphere work, thus bringing the best brains in the country together in order to achieve the best possible coordination for such a vast program. The five principal activities having the most experience and adequate facilities to carry out this coordination were: the Naval Research Laboratory, under the Office of Naval Research, the General Electric Company, the Applied Physics Laboratory, Johns Hopkins University, the Air Materiel Command, and the Signal Corps. All of these activities are supporting or coordinating the work of numerous other universities and agencies. The Office of Naval Research has contracts with a number of universities including Princeton, Harvard, Yale, Michigan, New Mexico A and M, Johns Hopkins and the University of Chicago.

The plan to use V-2 missiles as vehicles for atmospheric research gave rise to the need for the design and construction of special "warheads" suitable for the contemplated experimentation and other essential equipment for use in a rocket program. The warhead, or instrumentation section, which was specifically designed for the program permitted the experimental equipment to be assembled and installed at the laboratory and the entire assembly then flown or shipped to White Sands to be fitted on to the V-2 frame for firing. (This method is now used when firing the new Viking.) A tremendous amount of design work was necessary to provide electronic instrumentation for obtaining, transmitting, and record-

ing data. This included telemetering equipment for sending all information back to the ground stations during rocket flight, and other special purpose transmitters and receivers. A frequency modulated radio control system was modified to provide for cut-off of the rockets' fuel by an operator on the ground if the rocket should depart from its prescribed course and head outside the firing range.[1] In addition, specific equipments were designed and constructed for individual research experiments. These included a cosmic ray electronics counter, amplifiers for temperature and pressure measuring units and a three-channel ionosphere transmitter. All equipment had to be mounted so as to withstand an upward acceleration of 6 g's (192 feet per second, per second).

On 28 June, 1946, the Naval Research Laboratory fired its first rocket at White Sands Proving Grounds. This rocket, V-2 number 6, attained an altitude of 68 miles and carried instrumentation to determine the nature of primary cosmic radiation and to make temperature and pressure measurements of the upper atmosphere.

This flight marked the beginning of the "rocket era" for upper atmosphere research. At the present time the Laboratory has fired 13 V-2's, 6 Aerobees, and 5 Vikings, most of which have been successful. (Many NRL experiments have also been flown in rockets fired by other agencies.) Much data has been obtained, analyzed and reported. This information has contributed greatly to the nation's store of knowledge in this field.

It was recognized that the supply of the V-2 rockets would be exhausted in a period of about two years by the many agencies engaged in this field of research unless a new source of supply could be obtained. Although the V-2 is a good vehicle, it was designed as a long range weapon rather than as a high-altitude sounding rocket and, as such, has many shortcomings. Its greatest disadvantage is the lack of stability in flight and the fact that a 2000 pound payload is required for any degree of aerodynamic stability. It then becomes necessary to use ballast, in addition to instrumentation, in order to obtain a stable flight.

In the spring of 1946 the Naval Research Laboratory made a study leading to the design of a new high altitude sounding rocket. On the basis of this study, it was decided to develop a new rocket rather than to procure American-built copies of the V-2. It was found to be more economical to design a high altitude sounding rocket in accordance with the specifications drawn up, as a result of this study, than to make copies of the German V-2, modified to serve as an upper atmosphere research vehicle.

At about the same time the Naval Research Laboratory also collaborated with the Applied Physics Laboratory (Johns Hopkins University) which was under contract to the Bureau of Ordnance, Navy Department, in the procurement of a series of small rockets for sounding the atmosphere. The intention of this development program was to provide a relatively inexpensive rocket that would be able to carry a payload of 150 pounds, in a volume not exceeding 3 cubic feet, to a minimum altitude of 56 miles above sea level. It should also possess structural and stability characteristics that would permit it to carry a 300-pound payload at lower altitudes. This type of rocket is quite adequate to carry at least one worthwhile experiment in almost any field

[1] The Naval Research Laboratory has continued to supply the entire V-2 program with specially designed warheads, complete telemetering equipment and services, and complete radio control equipment and services.

Viking with South Fin Removed (Ready for Static Firing)

of upper atmospheric physics and in many cases will (and has) carried several experiments. The contract, sponsored by the Bureau of Ordnance, Navy Department, was awarded to the Aerojet Engineering Company of Azuza, California on 17 May, 1946, for the design, testing, and fabrication of 20 sounding rockets. The rocket was named the Aerobee. About 35 Aerobees have been fired to date. They have proven to be excellent and economical vehicles for certain phases of upper atmosphere research.

The specifications drawn up as a result of the special study of existing rockets and including the requirements imposed by the upper research workers, were submitted to a number of manufacturers. In the summer of 1946 a contract was awarded to the Glenn L. Martin Company of Baltimore, Maryland, for the development and construction of 10 high-altitude sounding rockets. The development and construction of a 20,000 pound thrust, liquid-oxygen, alcohol motor was individually contracted for with Reaction Motors, Inc., of Lake Denmark, N. J., through the Bureau of Aeronautics, Navy Department. This rocket, called the Viking, is a vertically launched, jet stabilized rocket which carries a somewhat lower payload than the V-2 (on an equal altitude basis) but is more flexible in its payload-altitude variation.

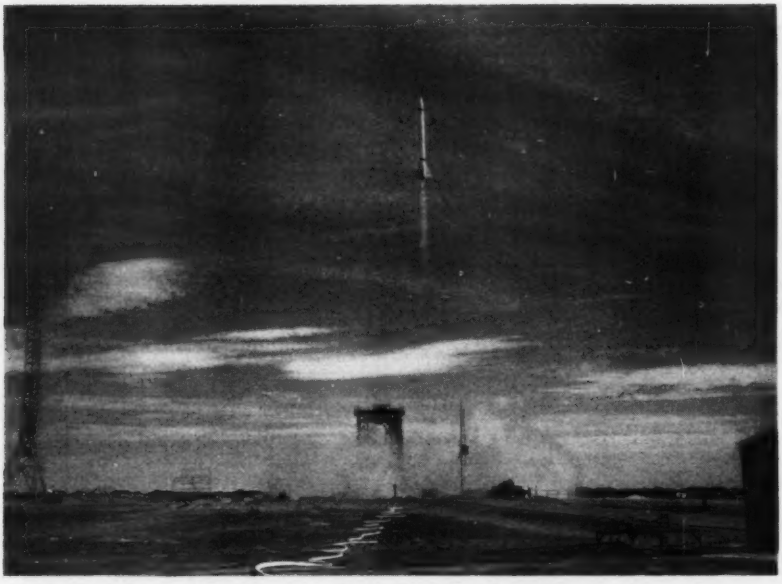
The basic policy of the Viking contract, prompted by the highly experimental and developmental nature of the work involved, provides that the design of each succeeding rocket shall be based on the experience gained from tests and firings of all preceding rockets. In view of the high percentage of failures in past rocket programs, it was stipulated in the contract that every reasonable and possible preflight test should be made to determine the performance characteristics of each assembled rocket before it is launched. This policy requires that the final assembly of each succeeding rocket can be started at the factory only when the Scientific Officer[2] at the Naval Research Laboratory determines what modifications are to be made in that rocket based on the "static firing"[3] and on the actual firing of the preceding rocket.

During the period of the Viking development the rocket experts of the Rocket Sonde Group at NRL divided their time between the Viking program and the job of modifying, readying, servicing and firing V-2 and Aerobee rockets. Upper atmosphere research went right ahead in all its phases. Special telemetering equipment[4] was developed which has now been adopted as one of the two standard pulse systems for all activities engaged in rocket probing of the upper regions.

[2] Mr. Milton Rosen is the Viking Scientific Officer for NRL. Much credit is due him for the success of the rocket.

[3] When a rocket is "static fired," it is bolted to its supporting stand to prevent take-off. Otherwise, it is fueled to capacity and allowed to run at full power until fuel burnout. The performance of the various systems and components of the rocket, i.e., the motor, controls and research instrumentation, is measured and analyzed under simulated flight conditions.

[4] The telemeter is an electronic system which translates information received from each instrument, such as Geiger counters, etc., into radio signals and sends it from the rocket in flight to a ground station. There it is received and recorded on film. These films are developed and are later taken back to the laboratory for analysis. From these records information is obtained on the rocket flight characteristics, motor performance, missile aspect and data from numerous scientific experiments. The system uses 30 channels and, by sub-commutation, 450 distinct messages or types of information can be telemetered continuously and simultaneously to the ground for recording.



Viking No. 1, Fired on 3 May 1949 at White Sands Proving Grounds to Altitude of 50.36 Miles

THE FIRST VIKING

The first Viking arrived at Oro Grande, New Mexico, from the Glenn L. Martin Company plant on 15 January 1949 (about two and one-half years from the time the contract was let) and was transported to the Navy technical area at the Naval Unit White Sands Proving Grounds where preflight tests were conducted by Naval Research Laboratory personnel. This included a bench test of components, functional tests of the control system and of the power plant. Upon completion of these tests on 1 February 1949, the rocket was moved to the launching site for a series of operational rehearsals. It was erected and aligned on the launching stand. Preflight tests were again made and servicing and firing rehearsals were conducted. The time required for each and every operation was recorded and procedures were established for use in actual static test and for flight operations to follow. This was America's first large American-built vehicle for upper air research and no firing procedures were known. Ground equipment was checked out. Test runs on fueling of alcohol, oxygen, hydrogen peroxide and nitrogen gas were made.

The rocket was then returned to the hangar and the nose (warhead) installations were completed. The entire rocket instrumentation was checked out and calibrated. An interference test in which all electrical components of the rocket are operated simultaneously was conducted and the rocket again erected

at the launching site on 25 February 1949.

In addition to instrumentation for upper atmosphere research, all Viking rockets carry instrumentation for determining flight trajectory, rocket aspect, power plant performance, skin temperatures, and stabilization system performance. These data are telemetered to the ground where they are recorded.

The determination of the rocket's trajectory as a function of time is of primary importance. Several of the contributory systems employed to determine trajectory are: a beacon installed in the rocket which emits a signal during flight. This signal is tracked by radars on the ground and provides bearing and distance data; a doppler radio system in the rocket and on the ground provides continuous velocity; a magnetically damped accelerometer mounted in the rocket responds to longitudinal accelerations and in conjunction with the gyro signals, by numerical integration, provides velocity and altitude; various gauges measure atmospheric pressures during flight. This pressure data is later compared with previously obtained data on the variation of atmospheric pressure with altitude and the rocket's altitude as a function of time may be determined. (This installation serves as a highly sensitive barometic altimeter).

Rocket aspect is obtained by optical tracking with telescopes located on the ground, by signals telemetered to the ground from the pitch, yaw and roll gyroscopes and by cameras flown in the rocket. The cameras obtain photographic records of the rocket's aspect with respect to earth coordinates.

Power plant performance is measured by various pressure pickups and a turbine speed tachometer whose outputs are telemetered from the rocket to the ground. With these pressure pickups it is possible to measure the performance of almost every component in the power plant, viz. turbine nozzle block pressure, pump pressures, exhaust pressures, etc.

Stabilization system performance is also measured by signal pickups from the gyros and recorded on the telemeter films.

Atmospheric and ambient pressure measurements are made. Temperature gauges are mounted along the skin of the rocket, on the control power supply and in the tail section near the power plant.

On March 7 the first attempt at static firing was halted when several electrical troubles developed. On March 8 and again on April 22nd and 25th static firings disclosed malfunctioning of components. Various electrical and mechanical troubles were eliminated one by one until tests showed the rocket ready for flight.

The Viking was launched at 0914 (M.S.T.) on 3 May 1949. It rose slowly, majestically! Lifted by its 20,000 pounds of thrust it gradually picked up speed until fuel burn-out. At that time it had attained an altitude of 14.6 miles and a velocity of 3450 feet-per-second (2350 mph). It soared on under its momentum to a peak altitude of 51.5 miles and returned to earth ten miles north of the launching site.

Telemetering of the data back to the ground was highly satisfactory. The Impact Computer predicted the rocket's impact almost exactly at its actual impact point. Fairly complete data on flight trajectory were obtained. Valuable upper atmosphere research data as well as complete motor performance data were obtained. The first Viking was a success!

It is true that the altitude hoped for was not attained, however the failure of the Viking to obtain greater altitude was caused by excessive heat in the power plant section. Postfiring investigations revealed that minute steam

leaks had caused damage to electrical wiring following which the power plant protective devices shut the motor off. The hydrogen peroxide generates the steam which drives a turbo-pump that pumps the alcohol into the engine where it is mixed with the liquid oxygen for burning. Computations based upon the amount of oxygen and alcohol remaining[5] in the rocket at burn-out indicate that a total burning time of 61 seconds would have obtained had the engine not shut off. This would have given a peak altitude of 98 miles.

The over-all results of this first Viking flight were particularly gratifying. It proved the soundness of the rocket design and of the motor. In addition it provided valuable upper atmosphere research data. If one should review all other attempts to develop and fire a new type of rocket, (The Germans, it is understood, required 200 test firings before the V-2 rocket went into production as a war weapon), the achievement of so successful a first flight would appear miraculous.

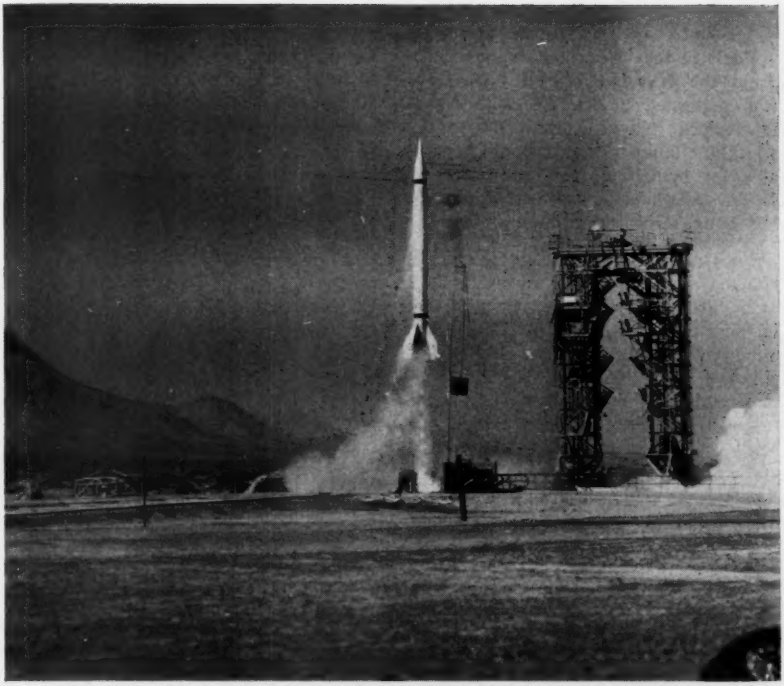
THE SECOND VIKING

On September 6, 1949, the launching and flight of Viking number two rocket was achieved at White Sands Proving Grounds. It reached a peak altitude of 33 miles which was considerably less than the predicted altitude. This was due to a premature cutoff in the propulsion system. However the static and flight firings produced significant data on measurements of rocket performance. Rocket-borne and range instrumentations functioned satisfactorily with the result that the Viking program was advanced substantially. The design of the rocket structure, power plant and control system was again shown to be sound basically. Photographs of the earth were taken at an altitude of 31.5 miles and atmospheric pressure measurements were successfully made during the flight.

The rocket was purposely severed by explosives at an altitude of 30 miles on its descent to facilitate recovery of film records and other instruments and components. Radio transmission (telemetering) techniques afford a fruitful means of obtaining data, however, some experiments require physical recovery of data. For example, data recorded on photographic film or radiation-sensitive emulsions must be recovered physically and be intact.

Based on computations that the two severed fragments would be aerodynamically unstable and would encounter much greater deceleration on their descent, it was decided to sever the instrumentation compartment from the after-body before the rocket, on its downward flight, reached the more dense atmosphere. This was done with explosives set off by radio signals. This method was very successful. Each section "maple-leafed" comparatively slowly to the ground. The nose cone was found in good condition about 2 miles east of the main body. The gas sphere and the rocket motor were found to be in a reusable condition! All cameras were recovered. Two of three X-ray densitometers were found in good condition. Three out of four films were found suitable for developing. Items that required recovery were painted a bright orange to make them more conspicuous. This greatly aided the searching parties in locating them after impact.

[5] The amount of fuel used (alcohol and oxygen) is continuously telemetered back to the ground station during flight.



Viking No. 3, Fired on 9 February 1950 at White Sands Proving Grounds to Altitude of 49.5 Miles

THE THIRD VIKING

Incorporating numerous modifications and changes, Viking number three was readied and instrumented by 7 February 1950, and was fired on that date. It carried a payload of 528 pounds of scientific instruments to an altitude of 50 miles. It was necessary, however, to cut off the fuel in the middle of the flight and bring the rocket to earth prematurely in order to insure its impact within the boundaries of the firing range.

The rocket kept programming westward and its flight was purposely terminated. This was done by radio controlled fuel cut-off valves which functioned perfectly on command. The motor was performing beautifully and telemetering signals were excellent. The rocket at the time of cut-off had attained a velocity of over 2000 miles per hour. Analysis of the records indicate that an altitude in excess of 100 miles would have been attained if the flight had not been halted. Excellent scientific data were received from telemetering records. The comparatively low peak altitude reached did not by any means spell failure from the standpoint of upper atmosphere research. A subsequent investigation and analysis of the records disclosed that the control system programmed the rocket in a westerly direction because of improper alignment of the pitch and yaw gyro, the fin-tabs, and because of inadequacies in the roll amplifier.

THE FOURTH VIKING

Early in the Viking development program the Naval Research Laboratory was requested by the Chief of Naval Operations, Navy Department, to design the Viking so that it would be suitable for launching from a naval vessel in order to test methods of launching large, stabilized rockets at sea.

The Navy in September 1947, launched a German V-2 from the deck of an aircraft carrier, the USS *Midway*, in the vicinity of Bermuda. This firing, although not successful from the standpoint of rocket flights, clearly demonstrated that shipboard launchings were feasible. The Chief of Naval Operations had designated as an experimental guided-missile ship the USS *Norton Sound* (AV-11), formerly a seaplane tender, and in the spring and summer of 1948 it was converted at the Naval Shipyard, Philadelphia, Pa., to be used as a facility for the evaluation of guided missiles and as a mobile launching site for scientific investigations using rockets.

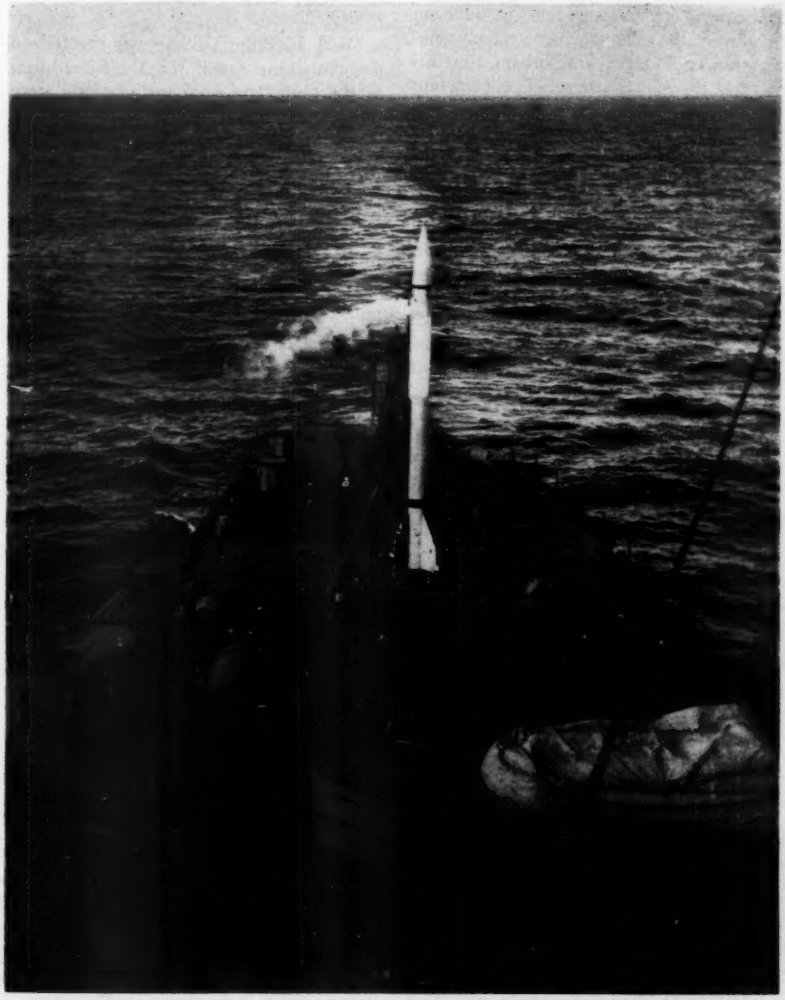
While the *Norton Sound* was being converted as a guided missile ship and during the development of the Viking, the Naval Research Laboratory went ahead with plans for a Viking firing at sea. A study was made of the handling and launching problems, and of telemetering, tracking, radio interference, and numerous other problems which would arise from shipboard operations which are not normally presented at the White Sands launching site.

Aside from any military value such an operation might have, the scientists were eager to fire from shipboard. This would permit studies of the atmosphere and high-altitude phenomena at geographic locations other than at White Sands, New Mexico. From indirect, ground-based operations, it was already known that upper-air phenomena vary markedly with geographic position. Confident that the Viking was now ready to fulfill its primary purpose—an upper air research laboratory—NRL in August 1949 requested the use of the USS *Norton Sound* (AV-11) for firing Viking rocket number four.

It was particularly desired to obtain cosmic ray data at the geomagnetic equator in order to measure the penetration of cosmic ray particles at that location. At the geomagnetic equator the earth's field deflects all particles eastward or westward depending upon their charge, except for particles having high energy. The Applied Physics Laboratory, Johns Hopkins University, scientists had conducted measurements from the *Norton Sound* at the geomagnetic equator off Peru in March 1949, using the medium-altitude research Aerobee rocket. By extending this work it was hoped to obtain more fundamental knowledge of the basic properties of radiation. It was also desired to measure upper-air pressures at the geographic equator.

The request to use the *Norton Sound* was approved and "Project Reach" was established. Its objectives were to launch an upper-atmosphere research vehicle for the study of cosmic radiation at the geomagnetic equator and to gain practical experience in the shipboard handling, launching and tracking of large bombardment-type missiles. The launching date was set as 10 May 1950.

To satisfy the requirements of the Cosmic Ray Group, who wanted to go to the geomagnetic equator, and of the Upper-air Pressure Group who wanted to conduct measurements at the geographic equator, it was decided to fire the rocket at the intersection of the earth's geomagnetic and geographic equators. This intersection, in the Pacific, lies at 160° West Longitude on the geographic equator, about 60 miles south of Christmas Island.



Viking No. 4 Fired on 11 May 1950 from the U.S.S. *Norton Sound* to Altitude of 106.4 Miles

Preparations for this project took about seven months. It involved changes to the ship structure, a new type launcher, electronic modifications for tracking, repackaging and installation of the NRL telemetering system, special power sources and others too numerous to mention here. The program was a coordinated effort with allocation of responsibilities for various phases of the project being given to several Naval activities. The Naval Research Laboratory was charged with the technical direction of rocket preparations, handling, launching, and tracking in addition to supplying all test and servicing equipment, the launcher and the rocket, and instrumentation for all upper atmosphere research experiments. The *Norton Sound* exercised operational and tactical direction and control of the project. The Bureau of Ships coordinated and performed the necessary modifications to the ship. The Bureau of Aeronautics supplied photographic coverage for documentation and was responsible for the design of the launching equipment.

After much hard work, many conferences, changes, modifications, designs, developments, more conferences and more hard work, the USS *Norton Sound,* commanded by Captain John Quinn, USN, sailed from Port Hueneme, California, at 1000 26 April 1950, with Project Reach personnel, headed by Dr. Homer E. Newell, Jr., NRL, aboard bound for that spot in the Pacific where the equators intersect. The destroyer, USS *Ozbourn,* detailed to assist in the operations primarily for tracking of the rocket's flight, joined up about 25 miles west of San Diego, California, and became a part of Project Reach Operations.

NRL scientific personnel, who had been aboard since early in April preparing the rocket and instrumentation for flight, were working day and night in an effort to meet a new and optimistic launching date of 5 May. The high humidity of tropical night air was a source of considerable trouble in the electronic circuits, particularly the high voltage circuits in the cosmic-ray experiments.

On 1 May the Viking was erected on the launching stand, on the after deck of the ship, and final installations were completed and it was ready for tests. The ship arrived in the launching area on 5 May—passing close aboard Christmas Island. A helicopter was sent in to inform the inhabitants of a proposed visit by personnel of the ships after completion of the firing.

Humidity and other troubles occurred and, although individually minor in nature, they were sufficient to cause postponements. In the meantime the ship maintained an operating radius within the firing area so that it could be on station at any time when the Viking was ready for take-off. Incidentally, the realm of Neptunus Rex at the geographic equator was crossed and recrossed numerous times. By special permission of King Neptune, the paying of respects to the Royal Court by Shellbacks, and the cleansing of the scurvy Pollywogs and initiation ceremonies were delayed until after the firing. (It is presumed King Neptune has no jurisdiction over the geomagnetic equator except where it intersects his domain).

On May 11, tests and checkouts proceeded to X-2 hours with everything clear and, from this point on, operations proceeded exactly on time.

At 1600 local time the Viking was fired. It roared up to an altitude of 105 miles, reaching a peak velocity of 5160 feet-per-second (approximately 3600 miles per hour). With almost a thousand pounds of payload this altitude could only be theoretically obtained if everything worked out perfectly. Optimum conditions of fuel, mixture, thrust, etc., were achieved. Viking 4 was a success! Project Reach was a success! The Viking splashed into the

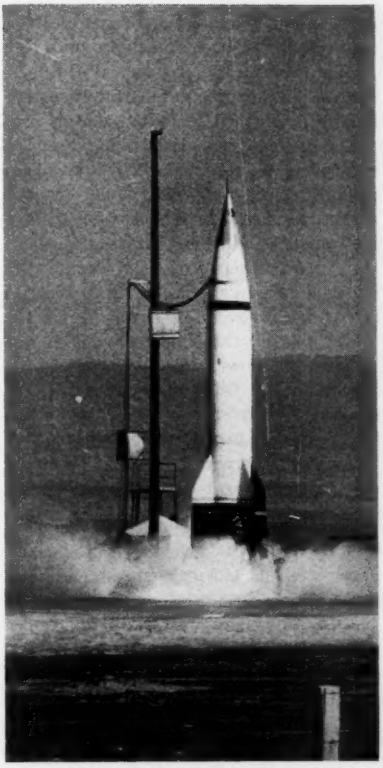
sea seven and a half minutes after take-off, a souvenir in Davey Jones Locker —a gift to King Neptune.

The objectives of Project Reach have been attained. Analysis of the scientific data recorded on the telemetering records have not been completed as yet but the information is available for study. Military objectives were met and step number four of the Viking development program has been taken. Much information was received on flight characteristics and motor performance which was useful in improving Viking 5 and will go to improve numbers 6 to 10. Invaluable training was received and the Navy's guided missile program has been significantly enriched.

King Neptune and his Royal Court came aboard on 12 May and hundreds of pollywogs were initiated into the Royal Order of The Shellbacks—included were Dr. Homer Newell and most of his scientists.

A visit was made to Christmas Island, where the natives and scientists found mutual interests—each about the other.

A stop-off in Honolulu of 3 days was made on the return trip back to the U.S.A. which was spent in sightseeing and relaxing in the Waikiki Beach area plus the usual trips about the island.



A V-2 in Preliminary Stage of Take-off

MORE ABOUT TODAY'S FLIGHT—VIKING 5

The flight of Viking 5 today was a continuation of the experimental test firing program. Data obtained on flight trajectory, rocket aspect, motor performance, stabilization before and after fuel burn-out, base pressure, skin temperature, and air temperatures in the tail section during powered flight are important to the rocket program and may affect the design characteristics of the next five rockets. All firings through number 10 are considered rocket test flights.

Included in the "warhead" were upper air research instrumentation designed to measure the electrostatic field at the rocket's skin; to determine the properties of the ionosphere by means of radio propagation and by direct measurements; to measure solar X-radiation by photo-emission, scintillation counter, ionization chamber and photographic techniques; and to measure atmospheric pressure up to the highest altitude obtained.

Excellent telemetering records were received throughout the flight until the rocket broke up at an altitude of slightly above three miles from the earth on the downward leg. For reasons, not yet explained, the explosives placed in the rocket to sever the instrumentation compartment from the body of the rocket, to facilitate recovery of certain instruments, failed to detonate. Apparently the rocket broke up due to the extreme speed and force of fall. It scattered debris over an area of several miles. Despite this, however, one aspect camera, three of six X-ray densitometers and one film transport densitometer were recovered in excellent condition. At least one item of each type of experiment for which physical recovery was desired, was recovered.

The film from the rocket aspect camera has been developed. It is complete, without a break, throughout the flight. It covered through the peak and almost all the way down before the film itself ran out.

Scientific records from Viking 5 are more complete and better than from any rocket previously fired. The scientists are jubilant! As one NRL physicist put it, "We have a pot full of data"—data awaited by scientists in this field of research throughout the world. It will be months, years probably, before all conclusions have been drawn.

Interspersed in the Viking rocket firing program for upper atmosphere research, throughout this period, were Aerobee and V-2 firings. These vehicles were necessary for certain types of experiments, in the case of the Aerobee, and in order to maintain a well-paced research program. Viking deliveries in the development program were not fast enough to provide an optimum research program and the V-2 was used to fill firing gaps in the program. Only four V-2's are now left, available to the program for firing.

WHY UPPER ATMOSPHERE RESEARCH?

The mystery of what lies beyond the earth's atmosphere has fascinated man throughout the years. Even in ancient times men wondered about heavenly bodies, were mystified by what they saw and held many superstitious beliefs as the result of their ignorance. Later telescopes were used and it was the Greek star-gazers who first observed that a few of the many heavenly bodies wandered across the sky instead of maintaining fixed positions. These bodies were called planets, a word derived from the Greek word "wanderer." As man has learned more and more about what lies beyond the earth's atmosphere he, more recently, has expanded his studies to include the earth's atmosphere itself.

Atmospheric research comprises a significant part of the nation's military research program. As the medium in which, through which and by which, men and most vehicles move, the atmosphere exerts an inescapable and sometimes controlling influence on military activities. An appreciable part of the atmospheric research is devoted to high-altitude research by means of rockets. As the region in which large rockets must fly, the importance of knowledge of this region to future military operations is considerable.

The Rocket Sonde Research Branch was established at the Naval Research Laboratory on 17 December 1945. Its function is "to investigate the physical phenomena in, and the properties of, the upper atmosphere." This program is the natural outgrowth of the Laboratory's work on the upper atmosphere during the two decades preceding World

War II, as well as its work on guided missiles during the war.

For many years various groups at the Laboratory had been doing research on the upper atmosphere including work on the ionosphere; pressure, temperature and composition measurements; sky brightness studies; and atmospheric electricity studies. The work of Drs. Hulbert, Gunn, Maris and Taylor since 1920 is widely known and their contributions to science in these fields well recognized.[6]

The aims of the Naval Research Laboratory's program are: to make valuable additions to the nation's store of basic knowledge; develop and train scientists in new and basic skills; and to produce new and useful instruments and equipments. This program has two phases: (1) upper atmosphere research; and (2) rocket research and development.

Phase (1) consists of basic research in cosmic rays, atmospheric pressures, temperatures and compositions, and ionospheric and solar radiation studies.

COSMIC RAYS

Little is known about the invisible electrical and related phenomena originating outside the earth's atmosphere which include cosmic and other types of rays. Cosmic rays are believed to consist of electrons, protons, helium nuclei and other minute particles traveling through space. These particles have enormously high energies and are continuously bombarding the earth. Cosmic rays having as much as a trillion electron-volts have been measured at sea level. Most of the primary particles are absorbed or broken up into secondary showers upon reaching the more dense earth's atmosphere. The source of these rays is unknown. It is known, however, that some solar flares or sun-spot activities cause an increase in the bombardment. It is possible that the basic physical knowledge obtained from the study of cosmic rays may some day be as important as fission of uranium is today. These studies form an important part of present day nuclear research. Using the rocket as a laboratory it is possible to observe and study particles having far higher energies than can ever be generated in the man-made machines, such as cyclotrons, betatrons, etc., in the research laboratories.

THE IONOSPHERE

The atmosphere may be said to consist of four gaseous shells; the troposphere, the stratosphere, the ionosphere and the exosphere. These gaseous layers are not marked by sharp changes in characteristics but are regions characterized by certain physical features. The ionosphere is that shell between the stratosphere and the exosphere. It exerts a great influence upon radio communication and is found to vary in heights between approximate altitudes of from 50 to 450 miles, subject to diurnal and seasonal variations. Ionization increases generally, with increasing altitude. Maximum ionization layers within the ionosphere are further defined by altitude levels and tempera-

[6] It might be mentioned that one of the "by-products" of the ionosphere work in those early years was a pulse modulator developed to measure the height of the ionosphere. This same pulse system was employed in, and might be called the heart of, RADAR which played an important role in World War II.

tures. The D layer, having normally slight effect upon radio communication, is the seat of fade-out disturbances which blank communications for minutes of time, is in the region around and slightly below about 60 miles. It lies in the temperature region of about 32° Fahrenheit. The E, F_1 and F_2 layers, consecutively, are more densely ionized and are at greater altitudes and in higher temperature regions. The F_2 or top layer is in the region of around 4000° Fahrenheit, at an altitude as high as 450 miles and has maximum ionization.

The ionosphere is closely linked with and directly affects communication along the surface of the earth; and to, from, and between, high flying rockets. It also influences the radio noise signals recently detected as emanating from the sun and regions of inter-stellar space.

TEMPERATURES, PRESSURES AND COMPOSITION

The temperature-pressure-composition studies are providing knowledge about the atmosphere which are of extreme importance in the design of rockets and aircraft. For example, skin temperature measurements enable rocket and missile engineers to efficiently design the skin of the rocket as to materials and thickness. Pressure and density measurements have been made up to 76 miles and from these measurements the atmospheric temperatures have been calculated. Pressure patterns are known to have an effect on the weather. Studies of the upper atmosphere pressure movements may lead to better understanding of the conditions causing weather. The motions of pressure areas may be the information that will lead to long range weather predictions over large regions. If vehicles, and possibly man, are to travel through the upper reaches of the atmosphere its composition must be better understood. Much has been learned in the past four years by direct measurements which before the use of rockets could only be arrived at by computations based on knowledge of the atmosphere at lower levels.

SOLAR RADIATION

The radiation from the sun is of vital importance to mankind. Until the advent of atomic power, all of man's major sources of power and heat (coal, petroleum, wood, water power, etc.) stemmed from the stored energy radiated to the earth by the sun. Much of the radiation is absorbed in the atmosphere producing effects, again of vital importance to man, such as the ozone layer, ionosphere, aurora and magnetic storms. If we did not have the ozone man would be exposed to dangerous ultra violet radiation. If we did not have the ionosphere, radio communication would be greatly complicated—long range radio communication virtually impossible. The spectacular aurora phenomena are associated with vast magnetic storms which often disrupt world-wide communication lines.

The investigation of solar radiation by rocket techniques sheds new light on the nature of these important natural phenomena. New discoveries have resulted from research using rockets as vehicles, such as the detection of soft X-rays and unexpected amounts of far-ultraviolet radiation. Further studies, now in progress, may eventually permit man to unravel the secrets of the sun and its effect on mankind through its control of the atmosphere.

Phase (2) of the NRL Rocket Sonde program includes basic research on rocket power plants, air frames and control systems, and the development of high-altitude rocket vehicles. This phase has been described in preceding paragraphs.

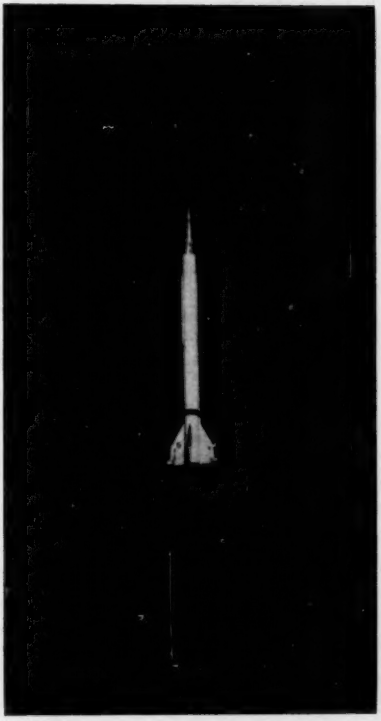
VALUE OF UPPER ATMOSPHERE RESEARCH

Fundamental research is the investigation of the fundamental laws and phenomena of nature and the compilation and interpretation of information on their operation. The upper atmosphere research program at NRL is fundamental or basic research. It is difficult, or impossible, to place value on basic research, when the end product can only be defined as "knowledge." Often, however, the by-products of basic research prove extremely important and more than justify the expenditures on the basic problem.

Some of the by-products of the NRL program have a security classification which prohibits mention here. Others, such as the pulse-time modulation telemetering system, the impact computer, new techniques for radiation detection, new and improved temperature and pressure gauges will find valuable usage in both military and civilian developments.

One of the by-products of the upper air research program that may achieve national significance is the Viking rocket. Already it has been approved by the Guided Missile Committee and the Upper Atmosphere Panel of the Committee on Geophysics and Geography of the Research and Development Board as the standard vehicle for extreme upper atmosphere research for all agencies engaged in research.

The success to date of the Viking can be attributed to the careful, painstaking, and step-by-step engineering development policy—learning to crawl before you walk, and to walk well before you run. Success is not yet attained or proclaimed. Today's firing was number five. Five are yet to be fired under the present development program. By incorporating the knowledge we have gained from all preceding flights into Viking number ten, its performance can be predicted to surpass the most enthusiastic of early predictions.



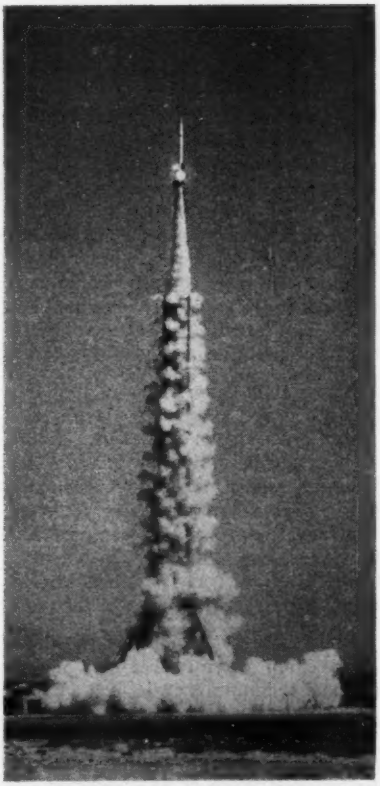
Viking No. 5 a Few Seconds After Take-off

A LARGER VIKING

A larger Viking is now being developed. Numbers seven through ten will have a height of about 45 feet and a diameter of 45 inches. This will increase the fuel capacity by at least 50 percent and should increase its altitude substantially, while carrying a payload of 500 pounds or will permit carrying

greater payloads—up to 2500 pounds—to lower altitudes.

During the time since the first rocket flight as a research vehicle, experiments have tended to become larger, heavier, and more complicated. In order to carry instrumentation which will give comparative measurements of data on upper atmosphere phenomena simultaneously or to carry a complete cosmic ray experiment which is necessarily heavy due to the amount of lead which must be used so that the penetration of the particles may be studied, and which is bulky due to the complexity of the instrumentation (over 300 tubes were used in the cosmic ray experiments in Viking 4), it was decided to develop a larger Viking. This larger outer-space laboratory, then, could accommodate the more complex experiments and will probably eliminate the need for additional flights which would otherwise be necessary in order to obtain comparative data or to carry partial experiments. In addition, the "super-Viking" should permit the study of the ionosphere to much greater altitudes. Scientists studying the ionosphere desire to make measurements up to and, if possible, above an altitude of 200 miles.



Aerobee-NRL-5, Fired 14 June 1949 to Altitude of 68 miles. Carried Spectrographs for Optical Measurements of Ozone Layer

Very little engineering development will be required to convert the present Viking to the larger size. It will be powered by the present 20,000-pound thrust motor. It should provide the upper atmosphere researchers with a more ideal vehicle for probing the earth's outer-space in their search for more knowledge about it.

STABILITY CURVES FOR NEW DESIGNS

STANISLAW R. UNIECHOWSKI

THE AUTHOR

STANISLAW R. UNIECHOWSKI obtained his Masters Degree in Mechanical Engineering at the Technical University of Warsaw (Poland) in 1930 and a Degree in Naval Architecture at the École due Génie Maritime, Paris, in 1935. He is a registered Professional Engineer in the State of Michigan and is a Member of the Institution of Naval Architects in England.

During sixteen years service with the Polish Navy he was employed in design and supervision of Naval construction and from 1937-39 was in charge of the Hull Construction Department in the Polish Naval Base in Gdynia (Poland).

During the last war he served with the Polish Navy in Great Britain as Constructor and Engineer Commander.

He is currently lecturing in Engineering Mechanics at the University of Detroit.

Mr. Uniechowski is the author of a Polish textbook on Theoretical Naval Architecture and the translator of numerous British Admiralty Engineering Manuals into Polish.

SUMMARY

The design of a new ship is generally made by altering the main dimensions (length, beam and depth) of another vessel of similar type.

The following method for deriving the curves of stability for a new design from those for an existing design obviates the considerable labor of drawing a new body diagram and working out GZ curves by integrator for various angles of inclination and main conditions of loading. Unlike the Wright's method, this method is an exact one and can be used for increases in both beam and depth. Furthermore these increases are not restricted to small amounts but may have any values, positive or negative.

The only assumption made is that the new form is derived from the old by uniform "stretching" in both vertical and horizontal directions, the ratios of alteration of dimensions having the same, or different values for the three principal directions. Lines parallel to the principal axes in the parent form remain parallel and mutually at right angles after stretching. Briefly the point (x, y, z) of the parent form becomes (λx, ψy, μz) for the derived form, the axes remaining rectangular.

It is necessary to draw auxiliary Cross Curves (see Appendix I) for the parent form, but once drawn, these serve for all forms derived from that parent form. As a numerical example auxiliary

Cross Curves (BZ curves) are given in detail for a ship of a destroyer type, hereinafter called parent form "A". Various constants which appear in the final equation have also been plotted as curves to facilitate the use of this method by reducing considerably the amount of calculation.

The method described in this article had first been suggested to me by Mr. D. C. Spanner, a British Naval Constructor, but despite its ingenuity is little known either in Great Britain or in the United States.

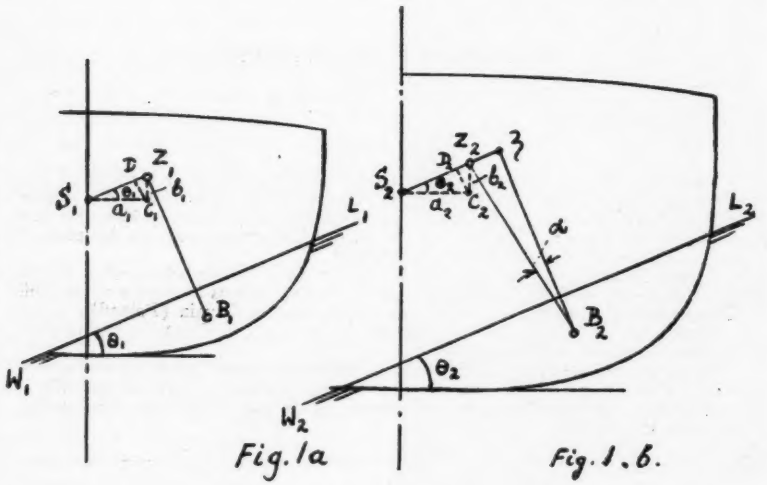


Fig. 1a Fig. 1b.

DESCRIPTION OF THE METHOD

Figure 1a represents the parent form "A" whose Cross Curves and Hydrostatic Curves have already been calculated.

Figure 1b shows the derived form, all horizontal dimensions being increased in the ratio λ:1 and all vertical ones in the ratio ψ:1.

The suffixes 1 and 2 indicate corresponding points in the two bodies, i.e., points whose abscissae and ordinates are in the required ratios. It may be easily proved by mechanical similarity, that, for instance, the horizontal coordinate of the centroid of the derived Figure G_1', is equal to the horizontal coordinate of the centroid of the parent form, multiplied by the common factor λ (Fig. 2a and 2b).

For Fig. 2a, $\bar{x} = \dfrac{\Sigma\, x_i a_i}{\Sigma\, a_i}$; if $x^1{}_i = \lambda\, x_i$

$$\bar{x}^1 = \frac{\Sigma\, x^1{}_i\, a^1{}_i}{\Sigma\, a^1{}_i} = \frac{\Sigma\, \lambda\, x_i\, \lambda\, a_i}{\Sigma\, \lambda\, a_i} = \frac{\lambda^2\, \Sigma\, x_i\, a_i}{\lambda\, \Sigma\, a_i} = \lambda\, x$$

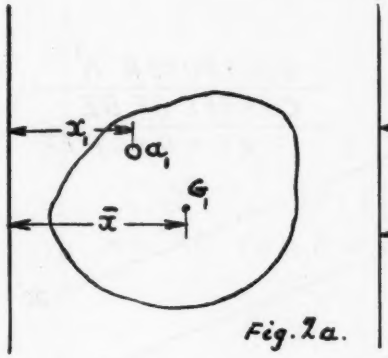


Fig. 2a.

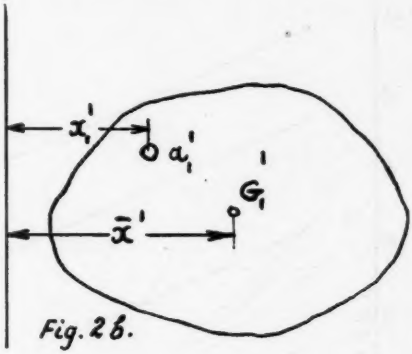


Fig. 2b.

From this it may be seen that while S_2, K_2, B_2 are points strictly comparable to S_1, K_1 and B_1 (for instance B_2 is the center of buoyancy of the derived form below W_2L_2), the point Z_2 is not, for stability purposes comparable to Z_1, since S_2Z_2 and B_2Z_2 are not generally perpendicular. That is, the inclination θ_1 and θ_2 of corresponding waterlines will nearly always be different.

To find the new value of the stability lever draw $B_2\ \eta$ perpendicular to W_2L_2 to meet S_2Z_2 produced, if necessary, in η.

Let $\angle\ Z_2\ B_2\ \eta = \alpha$. Thus we have: (See Appendix II for derivation.)

$$S_2\ Z_2 = S_1\ Z_1 \sqrt{\lambda^2 \cos^2 \theta_1 + \psi^2 \sin^2 \theta_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$B_2\ Z_2 = B_1\ Z_1 \sqrt{\psi^2 \cos^2 \theta_1 + \lambda^2 \sin^2 \theta_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\tan \theta_2 = \frac{\psi}{\lambda} \tan \theta_1 \quad \ldots\ldots (3)$$

$$\tan \alpha = \frac{\lambda^2 - \psi^2}{2\ \lambda\ \psi} \sin 2\ \theta_1 \quad \ldots\ldots\ldots (4)$$

Therefore we can write, that the new stability lever

$$S_2\ \eta = S_2\ Z_2 + Z_2\ \eta$$

$$S_2\ \eta = S_1\ Z_1 \sqrt{\lambda^2 \cos^2 \theta_1 + \psi^2 \sin^2 \theta_1} + B_2\ Z_2 \sin \alpha =$$

$$S_1\ Z_1 \sqrt{\lambda^2 \cos^2 \theta_1 + \psi^2 \sin^2 \theta_1} + B_1\ Z_1 \frac{(\lambda^2 - \psi^2) \sin 2\ \theta_1}{2 \sqrt{\lambda^2 \cos^2 \theta_1 + \psi^2 \sin^2 \theta_1}}$$

Put $Z = \frac{\psi}{\lambda}$; $m = \sqrt{\cos^2 \theta_1 + Z^2 \sin^2 \theta_1}$; $n = \frac{(1 - Z^2) \sin 2\ \theta_1}{2 \sqrt{\cos^2 \theta_1 + Z^2 \sin^2 \theta_1}}$

and it gives new $SZ = \lambda\ [m\ S_1\ Z_1 + n\ B_1\ Z_1]$ (5).

In the last equation $B_1\ Z_1$, is the only unknown variable. To obtain data for the entire family of forms based on the parent form, Cross Curves of BZ should be drawn for the parent form. From these, Cross Curves for the new design and ordinary stability curves may thus be easily drawn (see Appendix I).

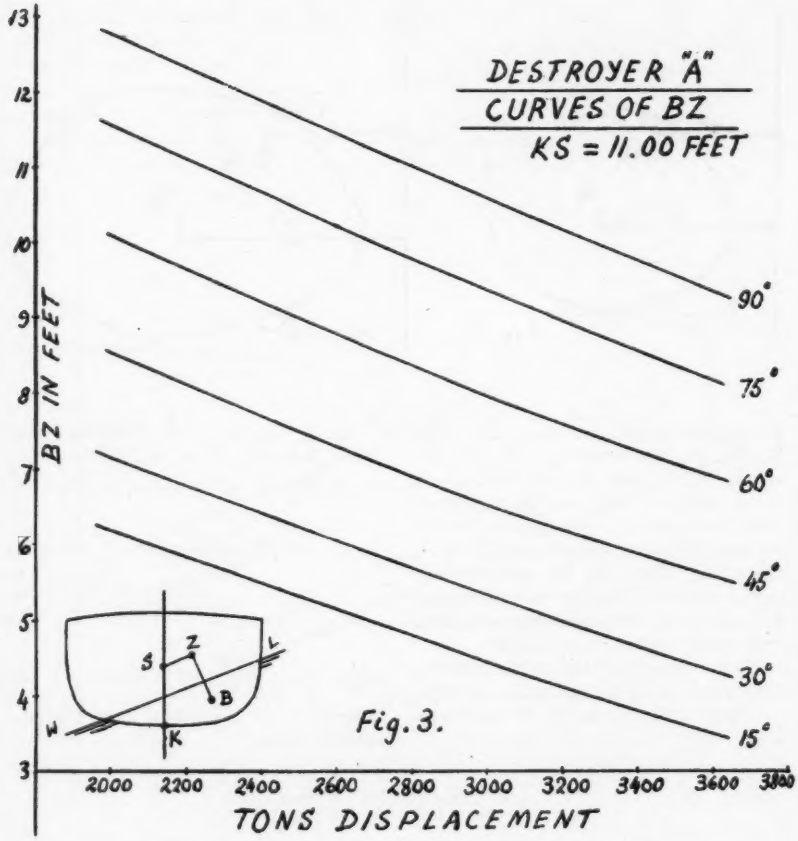


Fig. 3.

The following points should be noted:

(a) The pole height becomes

$$K_2 S_2 = \psi K_1 S_1$$

(b) The displacement corresponding to the new stability lever is given by

$$\Delta_2 = \Delta_1 \left(\lambda \psi \frac{L_2}{L_1} \right),$$

where L_2 and L_1 are the lengths of the two forms and Δ_1 is the displacement of the parent form.

(c) The angle θ_2 corresponding to the new stability lever will not usually be the same as that belonging to the parent form but will be given by equation (3).

(d) To facilitate calculation, curves of m, n, and $\theta_2 - \theta_1$ are given plotted against Z for all values of θ_1 used in type "A" Cross Curves (15°, 30°, 45°, 60°, 75° and 90°).

(e) Curves of BZ worked out for a destroyer type "A" may be used for all forms based on this design.

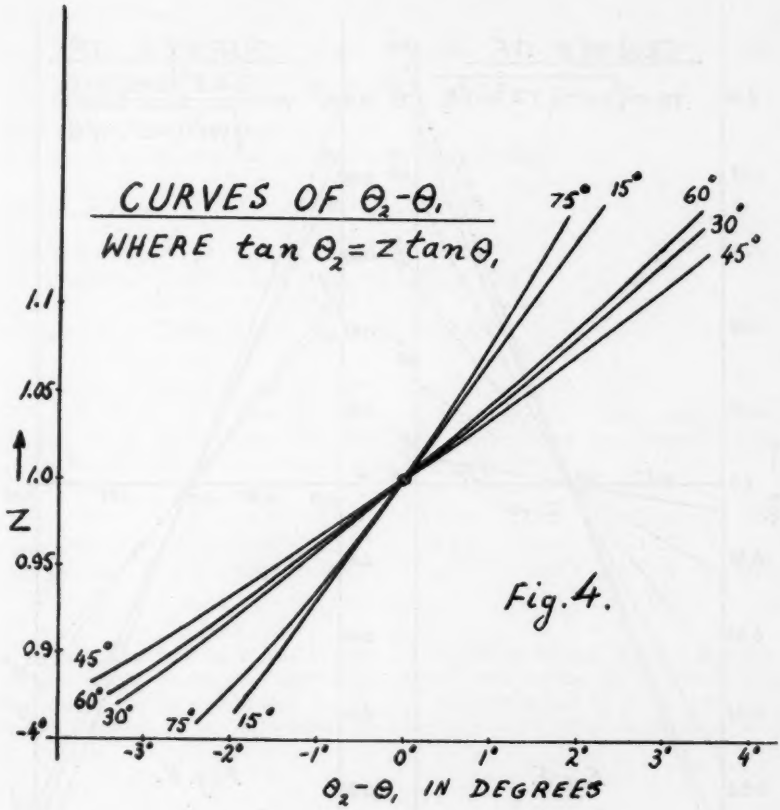


Fig. 4.

EXAMPLE OF THE USE OF THE METHOD

Destroyer "A" type

Length on W.L.	364′-0″
Beam	40′-3″
Depth	22′-0″

Destroyer "B" type

Length on W.L.	374′-0″
Beam	43′-0″
Depth	22′-6″
Light Displacement	3000 tons
KG	18.06′

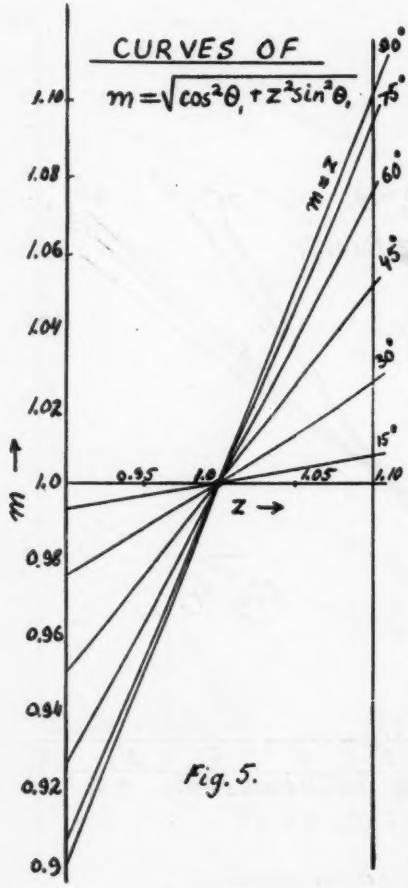


Fig. 5.

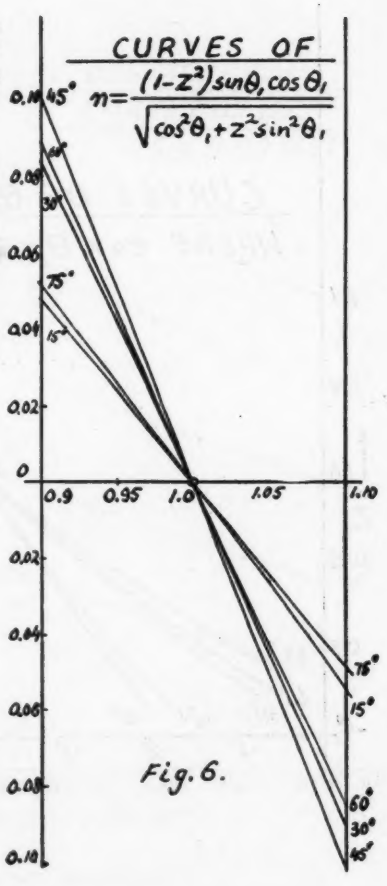


Fig. 6.

Destroyer "B" type is based on "A" type and all Stability Curves have already been worked out by one of the laborious methods commonly in use. We may therefore write:

$$\lambda = \frac{43.0}{40.25} = 1.0684$$

$$\psi = \frac{22.5}{22.0} = 1.0227$$

$$Z = \frac{\psi}{\lambda} = 0.9573$$

Corresponding "A" type displacement =

$$3000 \times \frac{40.25}{43.00} \times \frac{22.0}{22.5} \times \frac{364}{374} = 2668 \text{ tons}$$

$$K_2\ S_2 = 11.00 \times 1.0227 = 11.25'$$

15° Cross Curve.

$m = 0.997$; $n = 0.021$. For "A" type at 3000 tons $S_1 Z_1 = 2.28'$ and $B_1 Z_1 = 5.08'$.
Therefore $SZ = \lambda(m S_1 Z_1 + n B_1 Z_1)$ or
$SZ = 1.0684\ (0.997 \times 2.28' + 0.021 \times 5.08') = 2.54'$.
$\theta_2 - \theta_1 = -0.62°$ and $\theta_2 = 14.38°$.
Giving $GZ = 2.54' - (18.06' - 11.25')\ \sin 14.38° = 0.85'$.

30° Cross Curve.

$m = 0.9892$; $n = 0.037$; $S_1 Z_1 = 4.24'$; $B_1 Z_1 = 5.95'$.
$SZ = 1.0684 \times (0.9892 \times 4.24 + 0.037 \times 5.95) = 4.72'$.
$\theta_2 - \theta_1 = -1.075°$ and $\theta_2 = 28.925°$.
$GZ = 4.72' - (18.06' - 11.25')\ \sin 28.925° = 1.43'$.

Similar calculations for the 45°, 60°, 75° and 90° Cross Curves yield the results shown below, where they are compared with the figures obtained by the long method.

Comparison of values obtained by the above method and those from the long method:

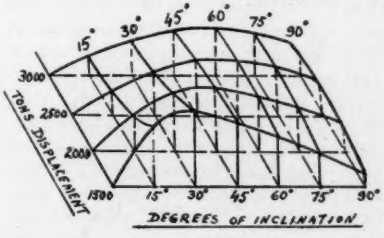
	$\theta_2 =$	14.4°	28.9°	43.75°	58.9°	74.4°	90°
Long method	: GZ =	0.87′	1.37′	1.22′	0.42′	—1.03′	....
As obtained above	: GZ =	0.85′	1.43′	1.25′	0.43′	—0.96′	—2.62′

From this comparison it may be seen that the results by the new method are as accurate as those obtained by the earlier method. The differences lie within the permitted limits of accuracy taking into account the possible errors of integrators and in the expansion of the body of the vessel in the mould loft.

APPENDIX I

Cross Curves of stability are the converse of the ordinary Curves of Stability. Instead of having the righting levers at a constant displacement and varying angles, in a Cross Curve the righting levers are calculated for a constant angle but varying displacement. The relation between the Cross Curves and the ordinary Curves of Stability is clearly shown on Fig. 7. On that diagram four curves of stability are plotted for a certain destroyer at displacements of 1500, 2000, 2500 and 3000 tons. These are placed as shown in perspective. Through the tops of the ordinates at any given angle a curve is drawn which is the Cross Curve of stability at that angle.

Fig. 7.



The auxiliary Cross Curves of BZ for the parent form can be easily obtained from ordinary Curves of Stability by means of Moseley's formula:

$$BZ = \frac{\text{Dynamical Stability}}{W} + BG \times (1 - \cos\theta)$$

Where the first term represents the area under the Stability Curve up to the angle θ and BG is a vertical distance between the Center of Buoyancy and the Center of Gravity of the vessel in an upright position. W is the displacement of the vessel in tons.

APPENDIX II

Let, on Fig. 1a, the distance $S_1 C_1 = a$, and $C_1 Z_1 = b$

$$S_1 Z_1 = a_1 \cos\theta_1 + b_1 \sin\theta_1 \quad \text{(I)}$$

From similarity, the corresponding distances on Fig. 1b

$$S_2 C_2 = \lambda a_1 \text{ and } C_2 Z_2 = \psi b$$

$$\text{Also } S_2 Z_2 = \sqrt{\lambda^2 a^2_1 + \psi^2 b^2_1} \quad \text{(II)}$$

But $b_1 = a_1 \tan\theta_1$ and substituting this value for b_1 in (I) and (II) the following is obtained:

$$S_1 Z_1 = a_1 \cos\theta_1 + a_1 \sin\theta_1 \tan\theta_1 = a_1 (\cos\theta_1 + \sin\theta_1 \tan\theta_1) \quad \text{(I)}$$

$$S_2 Z_2 = \sqrt{\lambda^2 a^2_1 + \psi^2 a^2_1 \tan^2\theta_1} = a_1 \sqrt{\lambda^2 + \psi^2 \tan^2\theta_1} \quad \text{(II)}$$

Divide (II) by (I)

$$\frac{S_2 Z_2}{S_1 Z_1} = \frac{\sqrt{\lambda^2 + \psi^2 \tan\theta_1}}{\cos\theta_1 + \sin\theta_1 \tan\theta_1} = \frac{\sqrt{\lambda^2 \cos^2\theta_1 + \psi^2 \sin^2\theta_1}}{\cos^2\theta_1 + \sin^2\theta,}$$

giving finally

$$S_2 Z_2 = S_1 Z_1 \sqrt{\lambda^2 \cos^2\theta_1 + \psi^2 \sin^2\theta_1}$$

Equations (2), (3) and (4) can be obtained in a similar way.

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1. Theoretical Naval Architecture by Edward L. Attwood, O.B.E.

SINGING PROPELLERS

A REVIEW OF MARINE PROPELLER NOISE AND VIBRATION STUDIES

C. E. WORK

THE AUTHOR

Received his B.S. and M.S. degrees from the University of Illinois. Since 1946 has been engaged in research in the field of Fatigue of Metals under the sponsorship of the Office of Naval Research and in teaching in the department of Theoretical and Applied Mechanics at the University of Illinois. Spent the summer of 1950 as a mechanical engineer at the Naval Ordnance Test Station in Pasadena, California and during World War II held a reserve commission in the U.S. Navy.

INTRODUCTION

One of the most puzzling problems to confront shipbuilders and designers in recent years has been the problem of the singing propeller. This phenomenon consists of audible sounds arising from the vicinity of the propellers of ships under way and is usually called "singing." In attempts to describe the sound, it has been referred to by an assortment of names such as grunting, humming, grinding, squeaking, squawking, rasping, twanging, sawing, metallic ringing, etc.

"Singing" began to attract attention about 1930 when airfoil sections were beginning to be used in the place of ogival (segmental) sections for propeller blades (15, 24d, 30)*. During this same period hull forms were undergoing gradual modifications, and changes taking place in propulsion machinery resulted in increased propeller speeds. It is therefore not certain which of the changes was primarily responsible for the appearance of the singing, particularly since noise of this type has been observed also from propellers with ogival blade sections (30). Singing may have occurred before this time without attracting especial attention (15, 26). It is reported that twenty or thirty years earlier an intermittent whistling sound was observed by Admiral Charcot in the Antarctic. This sound stopped when the engines stopped, but as the vessel steamed away it was not audible to men put ashore.

* Numbers in parentheses refer to references listed in the bibliography at the end of this report. "d" refers to discussion of paper indicated.

Singing has been exhibited by both solid and built-up propellers and none of the plan forms commonly used seem to be free from the possibility of singing (28). Model studies of singing have not appeared to be very promising since singing has been observed almost exclusively in large propellers. However, models would likely sing if tip speeds were reached equal to prototype tip speeds (3).

Certain phenomena (2, 38, 40) in other fields, for example dancing or galloping of wires such as transmission lines (7, 12) and aircraft flutter (36), are self-sustaining and similar in many respects to the singing of propellers. These other phenomena, however, seem to result from causes which are more easily distinguished.

Hunter, in his classical paper (26), opened the field for study of singing propellers. He made a detailed analysis of the design characteristics and operating conditions of the propellers on fourteen ships in an attempt to determine what caused singing. Of the vessels covered by his investigations, four were powered by diesel engines, one by geared turbine, and nine by triple expansion reciprocating steam engines. Cyclic speed variation of the engine could contribute to the disturbances favorable to singing, especially at lower speeds (47); however, in Hunter's paper and others, singing has been reported from the propellers of vessels with all three types of propulsion systems and from both single and twin screw ships. In fact, it has been observed in a propeller after the engines were stopped, with the ship still in motion (26). It is generally agreed that the disturbances leading to singing do not originate with the engines but arise from hydrodynamic sources at the propeller itself.

The noise resulting from singing vibrations may be so great that it makes the aft spaces in the ship unlivable and carries through the water so that the ship can be detected at great distances by underwater listening devices (11). However undesirable these sound characteristics may be, other phenomena which accompany or cause the noise are far worse. Fatigue cracks or actual fracture of the propeller blades and shaft, reduction in thrust and efficiency, erosion or corrosion of the blade surfaces, and undesirable vibration through the whole vessel are all associated with the singing propeller. The interrelationships among these factors are confused by special cases in which the singing observed was not accompanied by erosion of the blade surfaces or fatigue cracking, and other cases where singing was not audible despite considerable erosion and vibration severe enough to give rise to fatigue cracks. Studies of these different aspects of the problem have provided information regarding some factors which contribute to singing. It is the purpose of this paper to survey the work that has been published and present a bibliography of the papers pertaining to this problem and phenomena closely related to it. To make the bibliography most useful, in several cases where the original paper may not be readily available, other references have been included in which the same paper or an abstract of it may be found.

BELL AND CLAPPER EFFECTS

Hunter pointed out (26, 24d) that there were two parts to the problem, which he termed the "bell" and "clapper" effects. The bell effect was the elastic responsiveness of the propeller blades to vibration, and the clapper effect was the tendency of the hydrodynamic forces to excite the vibration.

Elimination of either tendency or sufficient reduction of both would "cure" the singing. In the research surveyed in this paper, some investigators attacked only one side of the problem while others attempted to reduce both tendencies. Elimination of singing of individual propellers has been achieved in so many different ways that little agreement has been reached as to which fundamental principles govern the singing action.

Bell—Not all vibrations of the propeller blades are accompanied by audible singing, but it is generally agreed that singing can be attributed to mechanical vibration of the blades (28). It should be understood that every underwater noise originating in the neighborhood of the propellers is *not* classified as singing. Other sounds representing variable pressure waves are often due to purely hydrodynamic phenomena. Noise from cavitation on the blades and other surfaces and from tip vortices can be readily picked up by underwater listening devices even though the blade vibrations are not of appreciable magnitude. General water noise from turbulence and waves may also be audible but are not directly associated with singing.

Limiting the problem to noise resulting from vibrations of the blades does not mean that the solution is necessarily a simple one however, as Burrill pointed out (6d), the blades could undergo any one of four types of vibration:

(1) Free vibrations; i.e., natural oscillations of the blade in a very general and unconstrained manner when disturbed.

(2) Forced vibration in which the vibration is definitely imposed upon the blade by external periodic forces with little relationship to the free vibrations of the blade.

(3) Resonant vibrations where the periodic disturbance comes into synchronism with natural motions of the blade which are thereby intensified.

(4) Self-induced vibration (or flutter) which, if once started, derives energy from the stream in such a fashion that vibration is sustained.

The pitch or frequency of the singing notes has been observed in several instances to agree with one of the natural frequencies of the blade, but is not usually in agreement with the period of exciting blows which are multiples of the rpm (24, 47). Singing pitches fall in the range of 100 to 500 vibrations per second. More or less discrete pitches of the order of 200 to 300 vibrations per second have been measured in several instances (6, 26). In general, the sounds from propellers are quite complex and include a mixture of harmonics of higher order. Frequently they are of a discordant nature, and hence can be more accurately referred to as noise rather than singing. Lambie reports hearing a rather high-pitched whistling (30), but considered it to be different from what is generally called singing. He attributed this whistling to the collapse of cavities in the wake abaft the propeller and not to vibrations of the blades.

The intensity and the quality of the sound produced is a function of the propeller speed. In some cases the pitch predominating is different for different ranges of propeller speeds (47). Some observers have concluded that the pitch increases in almost direct proportion to the propeller speed (19). In some cases a sawing or grinding noise can be heard continuously or sometimes it appears intermittently only once per revolution. The tie-up of singing with propeller speed and with the periodicity of hydrodynamic forces dependent on propeller speed is not clear.

Singing has been observed (28d) to increase in colder water (less than 70°F) and to be decreased when sail-

ing in tropical waters (above 80°F). Other cases have been reported in which the rudder position effected the singing and in some cases singing appeared to have increased with an increase of immersion when the vessel was loaded more heavily. In no case has noise been perceived from propellers operating in reverse.

No general agreement has been reached as to which one or ones of the four possibilities listed above is responsible for excitation of singing vibrations. Investigators supporting each school of thought have presented their opinions with the analyses of the cases within their experience, giving the logic by which they reached their conclusions. Attention has frequently been directed toward cases which could not readily be explained by some other theory.

Stevens (50d) suggested that the instances of singing could be divided into two broad classes, namely, those due to self-maintained propeller vibrations (type 4 above) and those which result from externally applied periodic forces associated with high and sharply changing wake (type 2 or 3 above). Several investigators (6, 9, 28, 47, etc.) have considered the flutter phenomenon as a possible explanation for singing but have not found conclusive evidence that conditions required for flutter are reached in operating speeds of marine propellers. Proponents of periodic force explanations of singing have had difficulty in establishing the existence of periodic forces with frequencies agreeing with singing pitches observed or which could be in resonance with natural frequencies of propeller blades. Such evidence would be welcomed (9, 25, 24d). Shannon and Arnold (47) studied the frequency of vortex shedding with the hope of correlating it with the natural frequency of the propeller blade. This, however, did not provide a means of discriminating between singing and non-singing propellers.

Free vibration of the blades at their own natural frequencies seems to be more generally accepted than any of the other types to explain singing. In general, vibrations set up by hammer blows show a mixture of frequencies depending on how and where the blade is struck (6).

The blades have been observed to vibrate with similar modes in both air and water when struck. The natural frequencies of blade vibrations are lower in water, however, because of the mass effect due to the inertia of the water set in motion with the blade and also because of hydrodynamic damping (25, 28, 34). The frequency for a given mode of vibration in water may be less than in air by the order of twenty-five percent (44) and is a function of the frequency itself in addition to other factors.

In the struggle for greater lift with less drag, the propeller blades developed are thin, relatively smooth, and without projections, sharp curvatures or indentations, in fact, quite ideal for singing. It is perhaps more surprising that some propellers *do not* sing than that some *do sing.*

A given propeller blade can have a number of different natural frequencies since it can vibrate in several different modes, depending on the distribution of mass, elastic stiffness, and exciting forces. Which manner of vibration is critical in singing has not been determined since observation of a singing propeller in service is so difficult.

Longitudinal vibrations of the blade would be at higher frequencies than ordinarily observed in singing. In the ordinary broad flat marine propeller blade, lateral modes respond readily to disturbances, and fatigue cracks have been found conforming to lateral modes (28). Davis (9) considered singing to be primarily a lateral butterfly type vibration and suggested that if striking a blade in air at various points around

the edge produces the same note for all points of impact, singing could be expected in service. On the other hand, if different notes resulted from blows at different points on the blade, he would conclude that it would be silent in service.

Vibration in flexural and torsional modes has been observed frequently (5, 6, 25, 50). Torsional natural frequencies seem to fall within the range for singing, but the frequency of flexural vibration depends to a certain degree on the radial component of acceleration field and hence would vary with the propeller speed. Certain special combinations of these modes are sometimes considered necessary before singing is to be expected. In general it must be concluded that a very complex vibration can exist as a combination of lateral, flexural, and torsional modes. Which mode of vibration is set up and therefore the quality of sound produced, depends on the blade section and plan form.

The vibration of a marine propeller blade is complicated by elastic, inertia, and hydrodynamic coupling forces which are quite complex in themselves. These coupling effects arise because, in blades designed for efficiency, the mass center of the blade, the center of percussion, and the center of pressure are off the bending axis.* As a result of these eccentricities the resultant of the ordinary pressure forces causes both bending and torsion. Even a vibration which begins as only bending receives a twisting moment as a result of the bending inertia of the blade. Any torsion of the blade or any flexural velocity in vibration (changing the velocity of water relative to the blade) changes the angle of incidence and therefore changes the magnitude and location of the resultant pressure force. This produces changes in both bending and torsional deflections but by differing amounts. Small coupling effects also result from torsional inertia, curvature of the bending axis, and variation of pitch along the radius (28).

Clapper—Free vibrations of the blades require blows or impulses to start them. These impulses are generally attributed to two hydrodynamic phenomena (41); cavitation (47, 51) and vortices shed from the edges (17, 28, etc.). The cyclic variation of the pressure forces per revolution as the blade changes depth or passes in the wake close behind fins, struts, etc., produces torsional and longitudinal vibrations of the propeller shaft. Vibrations from this source can frequently be observed throughout the ship itself. These variations in pressure are not, however, considered to be directly responsible for vibrations of the blade classified as singing. Gutsche (19) concluded that the disturbances arose as a result of variations in pressure on the blade caused by minor irregularities in fabrication of the individual blades and variations in thickness of blade sections. Particles of water impinging on the blade surfaces and other such forces are considered to have negligible effect compared to the large water hammer pressures produced by collapsing cavities (39).

There is some controversy as to whether disturbances at the leading edge or at the trailing edge are more significant in producing audible vibrations. It is known that by virtue of its position and usual shape, the tip of the blade is particularly responsive to exciting forces (26).

Shifting of the center of pressure as a result of the above phenomena and other variations in the distribution of forces has received considerable atten-

* The bending or flexural axis is defined as the locus of points through which the resultant of the external forces can be applied to produce bending without twisting.

tion (6), especially because of its importance in aircraft propeller noise and flutter (33). When the amplitudes and velocities of the vibration are sufficient to influence materially the angle of incidence and thus influence the resultant force on the blade, so-called negative damping can occur setting up self-induced vibrations.

Cavitation takes three forms (27) in the case of the marine propeller blades. Cavities form on the face or pressure side of the blade at lower speeds (when slip ratios are low) especially when blades are abnormally thick and close together. It generally sets in at the root because of blade interference and the thicker sections (16). Back cavitation may be either "burbling" (3, 49), i.e., the formation of roughly spherical bubbles on the back or suction side of blade (hemispherical if in contact with a flat surface), or it may take the more serious form of laminar edge cavitation which appears first in the vortices off the blade tips and develops into leading edge cavitation with greater tip speed and thrust.

During the stages of face cavitation and partial back cavitation, the propeller efficiency is not affected (43), but erosion, blade pitting, and probably vibrations occur as a result of the tremendous impact pressures (39) created when the cavities collapse on the metal surfaces. In the stage of fully developed back cavitation, the efficiency is reduced materially (and therefore this point is seldom reached in service) while blade pitting and vibration are essentially eliminated since the cavities are carried well beyond the trailing edge of the blades before they collapse.

It is generally recognized that a considerable portion of the cavities formed actually do collapse on the blade surface (49). What proportion of the total number this represents and how far along the blade the cavities move before their collapse depend on where they form and how fast the stream moves relative to the blade surface. These factors, along with the strength of cavitation, control the magnitude and location of the exciting blows arising from collapse of cavities. The modes of vibration of the blades are dependent on these blows. For certain ranges of propeller speeds, the proper combinations of these factors may occur so that singing naturally results, but for other ranges of speed the noise is somewhat different or disappears, perhaps reappearing again for still other combinations.

Forces developed at the edges have large moment arms for exciting torsional vibrations of the whole section, and thinly tapered trailing edges of many airfoil sections, being structurally weak, can respond independently to edge disturbances. When operating in reverse the flow is probably such that most of the cavities formed collapse in the wake abaft the propeller or possibly at points on the blade which are not responsive to the exciting forces.

Back cavitation cannot be eliminated for all propeller speeds, but it can be deferred to higher speeds by increasing the mean width ratio of the blade, reducing the thickness ratio of the outer sections, reducing the slip and angle of attack at the outer sections, and of course, by increasing immersion (16). In some cases the pitch is varied along the blade to reduce the angle of attack for the outer sections.

The vortices shed at the trailing edge are most severe if the edge is quite blunt (1). Their strength is reduced if the trailing edge is sharpened giving a gradual taper back to the edge to prevent formation of a void space. The frequency of shedding of vortices is proportional to the stream velocity, and therefore the frequencies vary continuously as the radius from root to tip of the blade and as the angular velocity

of the propeller (6). The lateral force exerted by these vortices is proportional to the square of the stream velocity. Nearly all propeller blades shed behind them a tip vortex. When the spin of this vortex is rapid enough cavitation occurs along its core. When the blade tip passes through a high local wake the tip vortex may be momentarily quite intense, causing a strong reaction on the blade which may set up vibrations (47). The strength of the tip vortex can be minimized by reducing the angle of attack and loading at the tip and by other means such as shrouding.

These hydrodynamic disturbances are more severe and set in at lower speeds when the flow to the propeller is not axial (21, 31) or if there are variations in the flow (6, 18). By virtue of its position the marine propeller acts in a curvilinear and turbulent stream. Cavities and eddies are shed from the hull and disturbances arise at the rudder post, struts, etc. These contribute to the general turbulence of the wake, making any calculated angle of incidence of the water to the blade only an average with the actual angle of incidence (23) different at different points on the blade and fluctuating at any given point with time. The pressure and wake velocity for each blade are functions of its depth below the surface and its horizontal and vertical position relative to the hull, struts, and rudder.

The degree of cavitation and the strength of vortices formed depend for any given angular speed of the propeller on the shape of the blade section and distribution of pressure along the blade surfaces. These hydrodynamic phenomena are more sensitive to the shape at the leading and trailing edges and at the tip than are thrust and efficiency.

The effect of depth of submergence on singing cannot always be isolated from other accompanying effects. Conn and Burrill (6 and 6d) have observed an increase in singing with depth, citing cases in which singing appearing only mildly on light load trials was noticeably more severe for greater submergence when the vessels were fully loaded. Other things being equal, cavitation should be less severe for larger static heads effective when propellers operate at greater depths. It has been reported that singing of submarine propellers observed near the surface decreased or disappeared completely at greater depths. Observations of an increase of singing with depth cannot be taken as proof that cavitation could not be responsible for singing. If the increase in immersion of the propellers is the consequence of increased loading then there is also an accompanying increase in drag which tends to reduce speed and increase slip. This tendency to make cavitation more severe would increase more rapidly than would the alleviating tendency from greater depth of submergence of the propellers. Shannon and Arnold suggest that deeper immersion may have some effect on the propagation of sound and therefore greater sound need not necessarily be evidence of more violent singing (47). Interaction with the after portions of the hull (32) which may also be critical in singing, would be affected to some extent by the loading.

CURES

Since so many factors are involved in singing and many of these are interdependent, the differences in technique for curing singing have been almost as numerous as the engineers who have investigated the problem. Complete procedures have been outlined for use in design which are intended to assure

silent propellers (23). Criteria have been presented which make possible analysis of existing propellers to determine with a high degree of separation which sing and which are silent (4, 9). It is clearly possible to take a very complicated approach to designing nonsinging propellers, but it is also possible to achieve the same end simply by taking advantage of the experience of others (14). Davis (9) suggests that the blade can be designed in the usual manner to give maximum efficiency, and subsequent minor modifications can be made to eliminate the tendency for singing if it shows up. A wide variety of possible modifications have been presented to eliminate singing, and many of them have been used successfully in particular instances.

Kerr, Shannon, and Arnold (28) recommend sharpening the edges of a singing blade, claiming that sharpening the leading edge helps reduce cavitation, sharpening the tip and trailing edge helps control the vortex action. Den Hartog (11) reasoned that sharpening would prevent the dividing point of the flow on the leading edge from jumping back and forth across the edge thus impeding any self-excited type vibration. Knapp and Hollander (29) found that cavitation in axial flow was less severe for models with gradually tapered noses than for those with blunt noses. It does not follow directly, however, that this advantage would be maintained for a wide range in the angle of incidence occurring in normal operation of marine propellers.

Sharpening has been used on many occasions to eliminate singing of marine propellers (25, 27, 47, 50, etc.). What constitutes a sharp edge for ordinary propeller sections is not exactly certain. Hunter (24d) mentions that a radius of 0.05-inch had been accepted as a compromise between theory and practicability. Sims (46) reports sharpening to successively finer edges, the thickness at the edge being reduced to one-eighth inch, then to one-sixteenth inch, and finally to one-thirty-second inch as one measure to eliminate singing.

Reduction in cavitation on blades of hydraulic turbines can be accomplished by suitable shaping (37) particularly at the nose. In several instances (10, 11, 13) it has been found that noise or erosion of runner blades in hydraulic turbines (Francis and Kaplan types) has been eliminated by sharpening the leading edges and giving a gradual transition from the nose back to the original blade surface. In hydraulic turbines like marine propellers, cavitation as evident from pitting or noise is worse for units with larger diameters and, of course, is worse for greater suction heads (8).

The possibility of reducing cavitation by proper rounding of the leading edge (4) rather than sharpening has some theoretical basis (22). Sharp edges are more prone to damage in handling and in service, and there is some disagreement as to their practicability. Kerr, Shannon, and Arnold (28) presented data from tank tests which showed that considerable beneficial hydrodynamic damping resulted when the edges were sharpened. A certain amount of additional damping of existing vibrations results from hysteresis (49) in the blade metal itself, especially in materials like cast iron and bronze.

Like flutter in aircraft, the vibration of a singing propeller can be reduced by increasing the structural stiffness of the blades (6, 15, 47d). The response of the tip can be reduced by increasing the breadth or thickness of the blade near the tip (4, 6) and Bell (3) found that wider blades did not cavitate as quickly as narrower blades. One writer (6d) suggested stiffening ribs for thin vibration-sensitive trailing edges. Additional changes in the blade section of a more involved nature have

been recommended for several reasons. Burrill (4) outlined a list of blade characteristics favorable to singing and a corresponding list favorable to non-singing. Mass balanced blades with the centroids of sections on straight radial lines from the root to the extreme tip were considered preferable to markedly skewed blades with curved blade center-line. Burrill also considered that in the blade section the position of maximum thickness, the fullness of the leading portion, the thickness ratio, and the physical thickness near the tail were fundamental to the elimination of singing (24d). Conn (6) called for a blade designed to give a fixed center of pressure or, since that could not be achieved, reduction of the travel of the center of pressure to a minimum.

Shannon and Arnold (47) found that the curvature of transition back from sharpened leading edges should be gradual and free from reversals of curvature. Davis (9) reduced the resonant qualities of propellers by manipulating blade widths and thicknesses to make the natural frequencies of different portions vary along the length of the blade. This could be achieved by removing small amounts of metal from the blade center or thinning toward the edges.

G. Hughes, after analysis of over 150 working drawings, set up a method for design of the form of sections between the leading edge and the position of maximum thickness for the outer part of the blade as a measure to prevent singing (23). He defined a relation Q involving the shape of cross section at the leading edge and the average real angle of incidence. His paper included critical values of Q separating singing from quiet propellers for single screw ships.

In a recent paper Lambie (30) discounted the theory that mass-balancing prevented singing (or flutter) in the case of ogival sections, but considered structural flexibility near the thin trailing edge of the airfoil section (not mass balanced) to be more likely responsible for sensitivity of the latter to torsional vibrations. He contended that blades with ogival sections also would vibrate if the slip ratio was low. His analysis of cases where sufficient data were available showed that in at least this limited number of cases, singing occurred when the slip ratio was below that required for maximum efficiency and did not occur when the slip ratio was high. He showed also the connection between low slip ratios and propeller shaft failures.

Many other methods have been attempted or proposed to cure or prevent singing by modification of the propeller. Burrowing tips were recommended by A. B. Stewart (28d, 47d) to control variable wake and enable the propeller to bore its way through ever-changing currents. Hunter (26) reported an attempt to cure singing by putting a series of lead rivets at regular intervals near the edge of the propeller blades.

Operating at the stern of the ship, propeller performance is influenced to a large extent by the wake. Bending of the stream lines around the after part of the hull, turbulence from vortices shed from the hull, struts and shafting, and other disturbances contribute to a mixed wake. The angle of incidence of the water to the blades is therefore far from constant; consequently, thrust, torque, pressure distribution, center of pressure, and cavitation, which are all dependent on the angle of incidence (28), vary in accordance with wake variation. Reduction of the variation of the wake would therefore contribute to quieting the propeller. This could be accomplished by modifying the shape of the after end of the hull (24, 48) by providing maximum possible clearance between the propeller and body post, rudder, etc., and by avoiding obstructions in the flow such as couplings before or aft the propellers.

Certain other precautionary measures such as accurate manufacture (19, 48) smooth finish on both sides of the blades (45), and accurate balancing have also been found necessary in order to assure silent propellers.

CONCLUSIONS

From the data presented and from the opinions expressed in the literature covered in this review the following conclusions regarding marine propeller noise are summarized.

These sounds, usually called singing, are the audible manifestation of mechanical vibration of the propeller blades. The blades may vibrate in any one of a variety of different modes more or less complex because of nonuniformity of thickness, the vibration being further complicated by the elastic, inertia, and hydrodynamic couplings involved. The exciting forces are believed to be hydrodynamic in nature, resulting from the impact of collapsing cavities formed primarily at the edges of the blade and from vortices shed. Although singing is generally attributed to free vibrations, it is not impossible that in some cases self-induced flutter type vibration takes place.

It seems probable that somewhat different factors are involved in various instances of singing for which conditions are different. It has been found possible to effect cures by attacking different aspects of the problem. It is likely that certain apparently different remedial processes actually produce the same effect in some instances but in others amount to basically different approaches.

It is felt that in order to prevent singing in marine propellers the following general precautionary measures will be beneficial:

a. Accurate manufacture of propeller blades with carefully finished smooth surfaces on both faces.

b. Maximum feasible rigidity of the blades to flexure, torsion, and lateral bending.

c. Sharply tapered edges at the tip, leading and trailing edges of the blades.

d. Operation under as great static pressure (depth) as possible.

e. Reducing tip speeds.

f. Increase in the uniformity of wake by modification of the after hull form, by reducing turbulence produced by obstructions, and by increasing the clearances between the propeller and stern fixtures.

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G. R. Stuntz, Jr., Naval Architect, David Taylor Model Basin, observes the testing of a model of a cargo ship from the personnel platform beneath the towing carriage.

CIVILIAN CAREERS FOR NAVAL ENGINEERS

ALBERT F. BIRD

THE AUTHOR

The author, a Panel Coordinator in the Equipment and Materials Committee of the Research and Development Board, recently completed fifteen years of service in the Bureau of Ships. MR. BIRD joined the Bureau in the Specifications Section from which he moved to the Turbine and Gear desk. Save for the World War II period which Mr. Bird spent in the Landing Craft Program for the Bureau of Ships, his career has been devoted to the Navy's Turbines and Gears.

Naval Engineering in the Bureau of Ships appealed to Mr. Bird shortly after his graduation from Massachusetts Institute of Technology in 1930 and has proven to be a satisfactory career for the reasons presented in his paper.

"This article written as an appeal to young engineers to accept employment in the Navy, is published in the JOURNAL because of the very modern view of the Bureau of Ships which it presents."

Young men, you with new engineering degrees, what a variety of careers lies open to you! New sciences and new looks on old technologies have created jobs that beckon to you from every industry. Courage and initiative forged by the emergency fill you with a dissatisfaction with old techniques and an urge to remake things on a progressive, modern pattern. With your ambition and training you demand a fair return on the investment you have made in money, time and hard work to secure the formal part of your education.

How to select the opportunity that promises you the greatest satisfaction—

that is now your problem. How do you appraise the different assets of a particular job? Do you value travel, wide acquaintance, working on design of the latest equipment, association with distinguished engineers, enlarging your formal education, generous vacations? If so, have you considered how the Navy presents to you an opportunity for an engineering career second to none?

Many factual job characteristics described here for the Bureau of Ships (taken as a typical example) are equally applicable to a great number of government bureaus, those of the Defense Department in particular. Pay grades are the same, promotion policies and opportunity are comparable, working conditions do not differ greatly. What you must appreciate as you compare jobs is the receptive attitude to new ideas and the spirit of team play you will find so gratifyingly integrated into the daily life of the Bureau of Ships.

The Bureau of Ships is that part of the Navy which imagines and plans new ships, supervises their construction and maintains them. It seems so easy to state these three functions, yet what a tremendous responsibility and what a lot of work is involved in carrying them out. Since World War II the keynote of the Bureau in all its branches is *modern ideas.* Staffs of specialists are breaking new ground in every phase of engineering from the radar antennae atop the masts of our ships to the sonar domes projecting beneath their keels. Most of these specialists need one or more of you to keep their thinking abreast of the newest and best that modern science has to offer. There are vacancies now in the Bureau of Ships and throughout the Navy, each vacancy an opportunity for your career.

Do you want to be happy? Then you must feel that in performing your life work what you are doing is worthwhile. The designing and building of the fleet and keeping it in powerful readiness is of paramount importance to the country. It must, therefore, be vital to you. Suppose an engineer devises a propeller which will power an aircraft carrier with two additional knots of speed. How bright is his glow of pride when that flat-top races vast distances in time to turn the course of a battle! Again, suppose a naval engineer in the Bureau plans a listening instrument that hears a submarine in time to turn the battle. How great is the nation's debt to him! Or, perchance, a naval engineer can help develop a turbine lighter and more powerful than any used in ships before so that tons of weight are saved for other things—and more missiles are carried. Enough more punch might be carried to win the day which might have been lost. Men, there is important work being tackled in the Navy and because of your training the country is looking to you to join the team and come to grips with it.

An engineer delights in working with nicely fashioned machinery and beautifully balanced apparatus. You will find stimulating satisfaction in handling such equipment in the Bureau. For a century, the Navy has progressively employed only the finest equipment that can be designed. Engineering study and experience have combined to demand in detail the best machinery and electric plant that the world can produce. That this apparatus must be continually improved is no reflection upon its designers but shows rather an aggressive effort by those same naval engineers and manufacturers to surpass their own masterpieces. Civilian naval engineers are battling in the thick of this improvement effort, using new alloys that glow red under operating temperatures, titanium, and the light alloys.

So, when you "come aboard" at the Bureau, you will not find hopelessly

Young Engineers operate an integrator in Naval Architecture Branch of BuShips.

obsolete units and antiquated old engines presenting glaringly apparent faults crying for change. Rather, you will find fine ships in which are excellent plants presenting to you a worthy challenge as you set about improving them.

Naval engineering differs in two important essentials from its commercial counterpart; variety in designs studied and degree of emphasis on dollar value. Engineers in private companies learn what they can of a competitor's product, but of necessity trade secrets are held closely by the companies and usually do not fall into competitor's hands. Thus, a commercial engineer's background is largely confined to his own firm's data. Naval engineers, on the other hand, must see, study and understand the proprietary practices and designs of all companies doing Navy business. A broad view of the entire field is thus laid before them.

Industrial manufacturers, designing with a sharp eye on cost and profit, are likely to consider a cut in quality to meet a price. Since the cost factor in naval machinery is subordinated to reliability, accessibility, light weight and economy, the Bureau engineer is trained to think of cost only after these other considerations have been satisfied. The Bureau insists on the finest quality product that can be made after a complete evaluation of competitive designs. Each apparatus is tailored to its task.

Naval engineering in the Bureau is varied. If your interests are in theoretical science, there is a place for you

TMB 43062 David W. Taylor Model Basin
10 June 1950

Mr. A. Campo, Engineering Aide, is checking to see that the model propeller is correctly mounted in the 12 inch variable pressure water tunnel where cavitation test will be run.

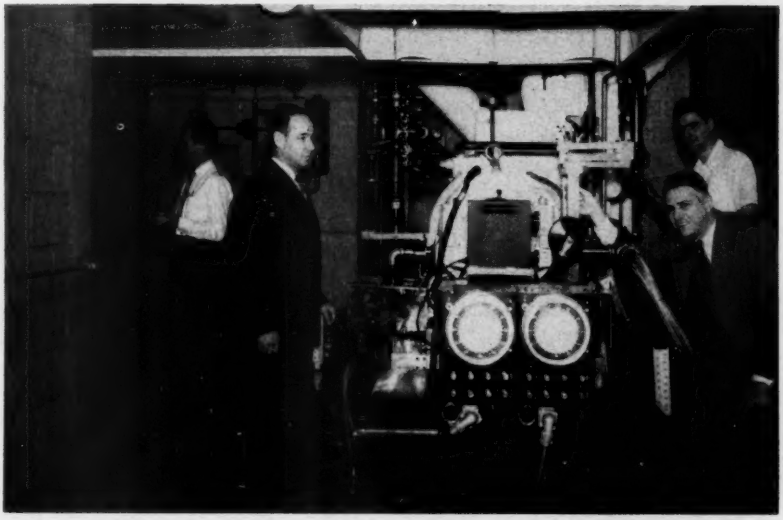
in a dozen "long-haired" groups who continually search for answers to countless puzzling problems. A little closer to actual design come the development staffs who calculate predicted ratings, performances, and efficiences of all sorts of apparatus from telephones to gas turbines. Still other jobs require analysis of proposals and plans from manufacturers. Such work will broaden your experience with mechanisms, strength of materials both cold and at high operating temperatures, electrical engineering, chemical engineering, thermodynamics, and will open to you a host of sources of information.

Electrical devices perform in thousands of places all over our ships. You engineers will find an opportunity in the Bureau to deal with intricate minute relays, electronic sensing circuits, ponderous generator sets, power transmission, distribution systems. At the same time, research beyond familiar knowledge is being extended to refine and modernize the electrical way of doing things.

Or you may "come aboard" in time to help inaugurate the era of nuclear power for ships. Here is a force new to many engineers which the Bureau is striving to utilize as propulsion power.

Broad though the Navy's research and development program may be, you as a Naval engineer will find it only a part of a truly vast network of study now under way by government agencies. Where possible, the Office of Naval Research and its far-flung investigations are used by the Bureau. The National Advisory Committee for Aeronautics contributes advice and other assistance to the Bureau from its wealth of engineering studies and extensive laboratories. All other branches of the government are available to the Naval engineer if he has curiosity and initiative to make use of their information and experience.

The Bureau of Ships likes young engineers who realize that a man's education is not sealed by a diploma. Truly, commencement, as the term implies, is a beginning of learning—learning to apply a man's formal education to the business of living. Soon after commencement a man learns how little he knows even of the specialty studied at college. The Bureau encourages you to study further by arranging courses in various engineering subjects given in the Navy buildings. Some courses are conducted on government time, others directly at the close of business for your convenience. These studies are voluntary and, if you wish, some of them on the graduate level, presented by several local universities, may be applied for credit toward advanced degrees. Also, as in any organization, your stature and capabilities indicated by mastering these courses are likely to be recog-



Journal Bearing Test Machine at Engineering Experiment Station, Annapolis, where Bureau of Ships Bearing Research programs are conducted.

nized by the Bureau in the form of increased responsibilities. If you wish to study a wider range of subjects, Washington is generously endowed with universities and schools of every character where many Bureau people take advanced degrees during hours after business.

Travel and a wide engineering acquaintance can be in store for you as a member of the Bureau's staff. To the Bureau comes the country's best engineering talent to present proposals for new machinery and equipment and to develop, with the Bureau, machinery and electrical improvements of every character. You, as young Bureau engineers, meet and exchange ideas with these industrial leaders. They are the men who pilot new developments into working mechanisms. In no other business would you be able to develop the wide industrial acquaintance that can be yours as a Naval specialist. Your position also qualifies you to mingle with these men socially in gatherings of professional societies such as the American Society of Naval Engineers.

As your projects under development reach milestones in their progress, you will be sent on field trips to witness tests and see new processes. Naval engineers with some years of Bureau experience have traveled to most industrial centers of the United States for periods of a few hours to several weeks. On occasion, industrial trips to Europe have taken Bureau engineers out of the country for months. The Bureau recognizes and fosters the need for breadth of vision in its young men as gained by travel.

Further traveling is involved in trials of Naval equipment afloat. On such trips you study your specialty in its ultimate function as a part of a formidable fighting machine. At the same time, you are able to observe all the other new and

startling devices that the rest of the Navy has been able to develop for that ship. The ship is the end product and in it you have the satisfaction of seeing the operating result of your imagination and hard work.

So much for the professional satisfactions which attach to your Bureau career. They are many, but there are still other advantages that a Naval engineer in the Bureau enjoys together with many government engineers in scores of Bureaus. These are the fiscal assets which are part of the job.

Your work week is a 40-hour† period at present spread over five days. Two-day weekends are a potent force in the enjoyment of spare time. The generous annual leave policy of 26 working days each year also gives you an opportunity for an extended vacation if you want it. However, unlike most companies, the Bureau allows the use of leave at almost any time if you can be spared from duty. A day or two off when you want it gives a genuine feeling of freedom. Sick leave provisions are likewise an important factor in favorable working conditions.

You are too young to think about retirement now. But, even so, let us see why we as young men try to save money. Isn't one reason so that we can have more things as we grow older? Insurance companies sell policies to you on the basis of a retirement income after you are 65. As a government engineer in the Bureau you are building an enviable fortune. At retirement age, if you are successful in your Bureau career, you will have an income such as could only come from a fortune in excess of one hundred thousand dollars. Or, stated another way, if you tried to buy equivalent insurance for retirement income, it would cost you $2300 each year from now until you reach retirement age. This capital asset is so attractive to Bureau engineers that it frequently spells the difference between private and government employment. The retirement plan is valuable to a man's family in the life insurance sense. It is really the essential nucleus of his whole financial security schedule.

Suppose that you cannot resist the appeal presented here and at 23 years of age join forces with the Bureau as a Junior Marine Engineer (GS-5), salary $3100. You are pleased with your opportunity and fit into the Bureau's scheme so that you may advance in grade and pay as shown by Table I.

† Since changed to 44 hour (Editor).

Table I

1	2	3	4	5	6
Years of Service	Grade	Salary *	Years in Grade	Cumulative Retirement Deductions	Cumulative value of deductions at 3% compound interest
1	GS-5	$3100	1	$ 186	$ 192
3	GS-7	3825	2	653	691
5	GS-9	4600	2	1,212	1,318
7	GS-11	5400	2	1,866	2,082
9	GS-12	6400	2	2,640	3,017
12	GS-13	7600	3	4,026	4,768
19	GS-13	7600	10	7,530	9,808
37	GS-14	8800	18	17,844	30,448

* This is the entrance rate of the grade. It will be increased $125 each year for the first six years through grade GS-9 and $200 each 18 months the first 7½ years for grade GS-11 through GS-14.

Young Bureau Engineers study main reduction gear model and dictate their conclusions.

Now, the money you have paid into the retirement system (column 5) is still yours, but in the quantities shown in column 6. If you choose to leave the government service prior to 20 years' service, you may withdraw your money, or, if you have had 5 or more years of service, you may leave it in the fund and receive an annuity at age 62. Not one cent of the money you paid into the retirement fund or the interest it has accumulated is ever lost. If annuity payments don't use it all and there are no potential annuitants remaining, the balance will be paid to survivors in a lump sum. Following are some examples:

If after 9 years of service with the record shown above, you leave the government, you may draw your $3,017 and consider it savings. Or, you may leave the money for annuity which you may draw at age 62 in the amount of approximately $770 per year.

But suppose you value your expanding career and work on until 12 years in the Bureau have passed and you have been in grade GS-13 for 3 of those years. You have built a family of a wife and three children, but you die—a gloomy picture, but you do. Now see the insurance aspect of the plan. Your family will receive an annual income of $1,548 until the children are 18 years old! After that your widow will receive $648 per year until her death or remarriage. It would take a lot of insurance to do this for them under any other plan.

Now look a long way ahead. You value your career more and more as years pass, and you neither leave the government nor die, and, in fact, you are promoted to a GS-14 grade from which you pass into retirement at age 62. You may choose between two ways of receiving your income: (a) Life annuity of $5,439 per year for life;

BuShips Gyro Specialist at work

(b) life annuity with survivorship provision for widow for life under which you would receive $4,970 per year until your death after which widow would receive $2,720 per year for the remainder of her life.

Now contrast these facts with your retirement income if you pursue a private employment career. The Government Social Security system now in force will assure you of an annual income of only $960 after 65 years of age. Your wife's 40 additional dollars per month from Social Security funds will boost the annual amount to $1,440.

Since you have twenty or thirty years of Bureau career ahead of you, it is probable that still further liberalization of the government retirement system will take place before you reach the age to use it. This improvement in your security will make your Bureau career all the more attractive *then* and therefore should carry weight in helping you decide *now* to join forces with the Naval engineers.

Last in sequence, but not necessarily in importance, comes the pay scale used for Naval engineers in the Bureau. For college graduates with little or no professional experience, the Bureau pays $3,100 per year (GS-5). Added years of college or years of professional experience of a suitable character raise the entering salary to a $3,825 or $5,400 level (GS-9 to GS-11). From these brackets on up to the $11,000 scale of top bracket Naval engineers, increases in salary are gained through acceptance of progressively increasing responsibility and authority.

Supervision in the Bureau is of a dual character in that both Naval Officers and civilian engineers participate in the administrative structure. Naval Officers selected for engineering duty in the Bureau possess an aptitude for engineering augmented by years of varied experience in engineering duty, both on shipboard and in shore establishments. Relationships between Naval engineers and their Regular Navy supervisors are refreshing because an outstanding performance by the civilian Naval engineer reflects credit upon his office, including all the Naval Officers in his administrative structure. Thus, supervisors, either Naval or civilian, value the young men highly and recognize the mutual benefit of increasing the young men's experience. Supervisors try to place responsibility on successful young men as rapidly as the load can be borne.

Electron Microscope at Engineering Experiment Station, Annapolis. This instrument is used in solving Bureau of Ships problems, such as elimination of Boiler Scale Deposits.

As you reach the close of this presentation, please ponder these advantages which a career in the Bureau of Ships holds out to you:

(a) You will do worthwhile work where the likelihood of your making a significant contribution both to your country's welfare and engineering in general is good.

(b) The engineering items you deal with are worthy examples of the art at the present stage of their development. As such, their improvement presents you a real challenge.

(c) Nowhere will you find a broader engineering experience than in the Bureau of Ships where excellence of design transcends dollar considerations.

(d) Your opportunities in broadening your formal education are varied and plentiful both in the Bureau and the city of Washington.

(e) Travel is an important part of your job.

(f) Wide acquaintance and friendship with the country's leading engineers is encouraged by the Bureau.

(g) Good working conditions and generous allowance of leisure time make you feel free.

(h) Your retirement income, the reason for such private saving, is more generous than industrial pensions and it carries with it insurance benefits otherwise available only at high cost.

REFERENCE

NAV EXOS-P-832. Scientific Personnel Employment Bulletin. Jan. 1951.

Official United States Naval Photograph

THE MOBILIZATION PICTURE TODAY

An address by Rear Admiral R. T. Cowdrey, USN, Deputy Chief of Naval Material, Navy Department, before the Southeastern Military-Management Conference, Atlanta, Georgia, 11 January 1951.

The mobilization picture today is one which portrays a complete realignment of the national economy. This realignment is designed to divert a sizable portion of the production potential of American industry from producing civilian items to producing military end items and equipment that are necessary to support the military preparedness measures of the nation. The scope of conversion of American industry is extensive because it involves not only the development of production capacity required to produce the weapons, equipment, materials and supplies needed to equip an Armed Force to upward of about 3,500,000 men but also the development of production knowledge, techniques and potential which will be necessary to support an all out mobilization of military strength in the event of a declaration of war. More important, conversion of the industrial capabilities of the production potential of industry to war production at this time is a warning to all aggressor nations of our military and production readiness, and therefore, should serve as a deterrent to war. Furthermore, the military preparedness measures now being taken should serve to buy time during which we may continue our endeavors to resolve the many world problems through the peaceful channels, available to all nations, and in so doing avert the calamity of a third world war.

The scope of my subject is so great that I am forced to restrict my comments to the mobilization efforts of the Department of Defense and their effects on industry. Since the declaration of a national emergency by President Truman on December 16, 1950, and the stated objective of building up to an Armed Force to upward of about 3,500,000 men, the three Departments are now stepping up their procurement program. Furthermore, the declaration of the national emergency has had an important effect upon the procurement procedures of the three Military Departments. Section 2(c)1 of the Armed Services Procurement Act of 1947 (Code 62 Statute 21) has been activated which is quoted in part as follows:

"Purchases and contracts for supplies and services made by the Department of the Army, the Department of the Navy, the Department of the Air Force, the United States Coast Guard, the National Advisory Committee for Aeronautics, and the Central Intelligence Agency, need not be made by advertising if determined to be necessary in the public interest during the period of a national emergency declared by the President or by the Congress."

In order to provide guidance for use of Section 2(c)1 of the Armed Forces Procuremeent Act, the Secretary of Defense has issued the following ground rules to insure:

(a) The greatest possible integration of current procurement contracts with the industrial mobilization program and the accepted schedules of production.

(b) The equitable distribution of procurement contracts among the maximum number of competent suppliers. The concentration of contracts with a few leader suppliers is to be avoided unless the necessity therefor is clear.

(c) The utilization of existing open industrial capacity to the maximum. Expansion of facilities should not be authorized when open capacity can be found. Whenever time permits, and in order to broaden the mobilization base, additional contractors should be utilized in lieu of multi-shift or overtime operation.

(d) The fullest possible use of small business concerns.

(e) The utilization in negotiation of competition and multiple awards whenever possible.

(f) The aggressive encouragement or requirements of subcontracting by prime contractors.

(g) The provision of maximum incentive to the producer for the reduction of his costs.

(h) The placement of contracts with a view to economics in the use of transportation facilities.

(i) The availability of manpower in distressed employment areas or in areas of manpower shortages, and

(j) The reservation of special skills and abilities for the more difficult production tasks.

Before discussing the application of the above mentioned ground rules to current procurement programs, a review of the current scope of miltary appropriations is considered important. When the Korean incident overtook us, our total defense appropriation for all three Services aggregated about 13 billion dollars. Since then, we have had about 12 billion dollars additionally appropriated, and a defense budget currently before Congress* is approximately 17 billion dollars more. If the 17 billions currently being requested for the Department of Defense are appropriated and added to the 25 billion dollars now available, the total would be 42 billion dollars. Of these monies appropriated or to be appropriated, I estimate that approximately 25 billion will be converted to production contracts, the remaining dollars being utilized to finance the operation of the Armed Services. With these background remarks in mind, I will outline for you how the ground rules, as issued by the Secretary of Defense, will be followed.

The first ground rule is one of the most important with respect to the mobilization planning of the Department of Defense. Since early 1947, the three Departments under the guidance of the Munitions Board have been embarked on a program of providing industry with a statement of mobilization requirements which would enable the various producers to determine their production loads in the event of an all out mobilization and to carry forward their internal peacetime planning covering the action they would have to take to effect a speedy transition to wartime production. As a result of this program, designated representatives of the three Departments have contacted the representatives of industry and have arrived at specified production schedules for military end items in the event of mobilization. It has been determined by the Secretary of Defense that it is now necessary to commence meshing the current procurement programs with the industrial mobilization plans. Therefore, the three Departments will (insofar as the current military procurement programs permit) place contracts with the producers who have agreed to produce specific military items in time of mobilization.

* Subsequently approved.

I wish to emphasize, however, that the meshing of current procurement programs into the industrial planning programs will not result in the elimination of qualified bidders for military business who have not been included in the industrial mobilization planning program. As set forth under ground rules (b) and (c) the military departments are to provide for equitable distribution of procurement contracts among the maximum number of competent suppliers and to utilize existing open industrial capacity to the maximum. Under ground rules (b) and (c), the procurement activities will be contacting all qualified suppliers in order to develop as many sources of military items as possible under the current programs.

In the speed-up of military procurement, the small business enterprises have not been forgotten. It has been, and will continue to be, the policy of the Department of Defense, that small business concerns do in fact participate in military procurement, both at the prime and subcontract level. The Departments know the degree to which small business concerns secure prime contracts and participate in the subcontracts. Therefore, it is the policy, as outlined in ground rules (d), (e) and (f), to obtain not only the fullest possible use of small business concerns but also to encourage sub-contracting by prime contractors.

The remaining ground rules (g) to (j) inclusive require the procurement agencies to take into consideration such important factors as transportation, manpower in distressed employment areas, and reservation of special skills and abilities for more difficult production tasks.

In conjunction with the speeding up of military procurement, the military departments are also assisting industry in meeting this challenge. Under Title III, of the Defense Production Act, the Departments have been authorized to make provisions for participation in guarantees of loans to private enterprises (including research organizations not organized for profit) for:

a. Expansion of capacity

b. Development of technological processes, and

c. The production of essential materials, including the exploration, development, and mining of strategic and critical metals and minerals.

In determining what form of financing should be made available to suppliers by the government, the following preference generally is observed although there may be valid exceptions in specific cases:

a. Progress or partial payment

b. Guaranteed loans (with financing institutions participating to an extent appropriate to the risk involved)

c. Advanced payments, and

d. Direct loans.

The Guaranteed Loan Program, which is concerned with short-term working capital requirements, was previously initiated during World War II and it was known as the "V Loan Program." Losses were negligible and the Federal Reserve Board March 1946 Report on this subject indicated that the over-all operation showed a profit. Loans of this type are again available to suppliers under Regulation V, Federal Reserve Regulations, as reissued, effective September 27, 1950.

The three Departments are further cooperating in every way possible with the contractors, the banks, and the Federal Reserve Board in order to assure that defense production is not retarded due to lack of adequate financing. The second type of financing available to industry, namely, direct loans to contractors made through the Reconstruction Finance Corporation, are in the nature of capital loans as contrasted with short term working capital loans under the "V" loan program just discussed. In fact, the application form for

direct loans states they must be "for such major purposes as land acquisitions, building construction, purchase of plants, purchase of equipment, etc.," The RFC acts as agent in making direct loans as these loans are similar to other types of loans customarily handled by that agency to assist heavy industry or other business in obtaining financing not procurable elsewhere on reasonable terms.

The procedure to be followed in making application for a direct loan has been set forth as follows:

a. Applications should be filed with the Department of Commerce, Department of Agriculture, Department of Interior, or the Defense Transport Administration, whichever has the primary interest in the facilities, products, or processes involved. However, for convenience of the applicant, he may file with any government agency with which he has contact or other pertinent relationships and such agency will arrange for the transmittal of the application to the appropriate office. The last sentence of the foregoing would, of course, cover the Department of Defense, although it is not specifically named. For example, if an application is made to the Navy Department, the application is forwarded with appropriate comment to the National Production Authority, which in turn prepares a proposal for certification by the National Security Resources Board and forwards the application to the latter agency.

b. If the National Security Resources Board approves the application, it is returned to the delegate agency, which, in turn, transmits the certification to the RFC which acts as agent in making the loan after release of the funds by the Bureau of the Budget.

A contractor requesting a direct loan may file application with any of the field offices of the certifying agencies, which, in turn, will transmit them to the proper office in Washington. Generally speaking, this type of loan is an expedient resorted to only after other types of financing have been denied, or the specific purpose for which the funds are sought is of such a character as to properly belong in this category.

Before leaving the general subject of financing, it seems appropriate to digress for a moment and speak about Necessity Certificates, which permit accelerated amortization under Section 124A of the Internal Revenue Code as this has a bearing on broad financial operations.

First, I should like to define in this connection two terms: (1) Necessity Certificates, and (2) Emergency Facility.

"Necessity Certificate" is a certificate made pursuant to Section 124A of the Internal Revenue Code, certifying that the construction, re-construction, erection, installation, or acquisition of the facilities referred to in the certificate is necessary in whole or in part in the interest of national defense during the emergency period, and certifying the portion thereof attributable to defense purposes.

"Emergency Facility" is any facility, land, building, machinery or equipment, or any part thereof, the construction, reconstruction, erection, installation, or acquisition of which was completed after December 31, 1949, and with respect to which a Necessity Certificate has been made.

Several criteria have been set up for determining when it will be appropriate to authorize use of Necessity Certificates for accelerated amortization of emergency facilities. Some of these criteria can be outlined as follows:

a. The material or service to be produced must be required in whole or in part in the interest of national defense during the emergency period;

b. There must be an existing or prospective shortage of facilities for the

production of the materials or services sought to be certified; and

c. Consideration must be given to the probable economic usefulness of the facility for other than defense purposes after five years.

There are other general factors but the foregoing indicate the approach to a determination and provide enough background for considering procedures. The other general factors are:

(a) All applications are to be filed with the NSRB in Washington and must be on file before* March 23, 1951.

(b) The application is then referred (through the NPA) to the Department having a preponderant interest in the situation for recommendation and report. In all cases where the Navy has preponderant interest, the Office of Naval Material will coordinate the processing work by the various bureaus.

(c) The recommendation and report of the Department having preponderant interest is returned to NPA which forwards the application to NSRB, with its own recommendation for appropriate action, affirmative or negative; and, finally,

(d) If the action by NSRB is affirmative, a Certificate is issued and forwarded to the Commissioner of Internal Revenue. This certificate constitutes evidence that the facilities are necessary in the interest of national defense to the extent certified.

Briefly, I would now like to mention priorities. The main purpose of the priority rating system is to assure that military requirements are met before civilian needs. Furthermore, such a system assures the ability of the prime contractor to obtain the necessary materials. As was expected, there has been the inevitable confusion in certain aspects of the priority rating program to the extent that clarification of regulations and procedures has been necessary. Confusion has been experienced primarily in connection with items excluded from rating authority procedures for handling government-furnished equipment, interpretation of definitions, etc. On the whole, the American economy and the military demands on same have been handled astonishingly well, which is probably due to the fact that actions to date have been based on World War II experience.

Now that the world situation has become more critical, it is reasonable to expect that all forms of government controls will have to be more stringent. While it is beyond the power of any one individual to predict accurately the course of coming events, it seems entirely reasonable to anticipate that all forms of controls, i.e., wage controls, price controls, rationing, etc., will be implemented. As to when such will take place, I cannot predict.

The Military Departments are doing everything in their power to speed up the placing of contracts with industry in order to bridge the gap of conversion from civilian production to military production. American industry must produce the items required for our preparedness for peace and the Military Departments must assist whenever possible—we must be a team, a team for preparedness.

* If construction was started prior to December 23, 1950. If started later, the application must be filed within 3 months (Editor).

Prehistoric man was the first to sound a river bottom.

THE EVOLUTION OF DEEP SEA SOUNDING METHODS

A summary of the important events in the history of sounding

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THESIS

Man has long been vitally concerned with the depths of bodies of water. His progress in science and engineering is shown on a small scale by his improvements in the methods by which he can determine the depths of the sea. And the increase in his knowledge of the physical world in which he lives, brought about by his progress in science and in engineering, is in turn shown by the effectiveness of his present-day deep sea sounding equipment and techniques.

What is the shape of the bottom of the ocean? We know what the top looks like, but what shape does the bottom take? Is it a broad, flat plane, over which ocean currents can sweep in any direction, like winds over a desert? Or does it have deep places, and shallow places, and mountain ranges and gullies that can channel ocean currents in specific directions continuously, and in this manner affect the climate and winds over land and sea? Thanks to the painstaking efforts of mariners and oceanographers of the last century, and to the progress of our scientists and engineers of the past forty years, all of those questions have been answered. Contained in navigational charts and in data books, the answers are available to any person who will go to the trouble of writing for them.

The story of the development of the navigational chart as we know it today is largely a story of the development of means by which the depth of ocean at any point was determined. For the most important basic information required at the outset was that of configuration of the ocean bottom. Ocean currents, much like rivers on land, follow the low points to a large extent, carrying cold water or warm water great distances, and affecting the winds and weather in far-away places.[1]

How long has man been sounding the depths of bodies of water? What has been the order of development of equipment and techniques used in sounding? If by "bodies of water" we mean oceans, and if by "depths" we mean deep water such as that found only in the oceans, the answer to the former question turns out to be considerably less than 200 years. If, on the other hand, we include the shallow waters of the oceans, the continental shelves, and the waters associated with river mouths and harbors, the answer is something over 5,000 years. But, although we will concern ourselves in this paper primarily with the oceans, for a complete history of sounding we must include rivers and lakes. And if we include the rivers and lakes, we find that the true answer to the first question can come only from an archaeologist who can establish the date, in deep antiquity, when prehistoric man made his first raft. In answer to the second question, we can show that there was indeed little development in the art during the period from the Stone Age in Europe down to the nineteenth century; that during the nineteenth century some worthwhile progress was made; but that the systematic improvements made during the last forty years have exceeded the wildest dreams of the hydrographers of any earlier period.

What would Captain Maury have done had he dreamed of a modern Fathometer? It was Captain Maury who proposed the cannonball-and-twine method of deep sea sounding to the hydrographers of a hundred years ago. What would prehistoric man have said? What were the methods of prehistoric man?

There can be little doubt that prehistoric man was the first to use a method of sounding the depth of water. Although we know really very little about him, we do know that he migrated across continents, crossing rivers as he went. His first water-going craft was fashioned of logs, sticks, reeds, or other light-weight material lashed together to form a raft.[2] Next probably came boats fashioned from whole logs hollowed out. Such boats have been found associated with the lake dwellers of Switzerland, dating back to the Neolithic Age.[3] We may safely assume that by the time man had developed intellect enough to lash logs together to form a raft he had learned that he could make his craft move against the current or across the stream by pushing a long stick against the bottom of the stream or lake. For, without some means of propulsion, he had no incentive to build a raft, and

poling was the most obvious and simplest means of propulsion. Millenniums later, possibly within the broad period of the Stone Age in Europe, he probably discovered that he could stop or anchor his craft by dropping a stone tied to the end of a vine or crude rope, if he retained the other end. Surely it is reasonable to assume that the lake dwellers had occasions to anchor their boats. And in propelling his craft by poling, and in stopping it using a crude anchor, prehistoric man discovered two methods by which the depths of water under his craft could be sounded. For, although he had no standards of length, by observing intuitively the relative amount of stick or rope which descended into the water, could he not perceive the depth?

The earliest ship of which we have any knowledge, the earliest vessel capable of traveling over an ocean, was the Egyptian galley of about 3000 B.C.[4] This was a fairly large craft, as judged by the standards of the day. Surely there must have been some means by which the captain was assured he was in deep water. For, although propulsion depended on oars, the vessel could attain enough momentum to be used as a ram, to smash in the side of an enemy vessel. Such momentum, applied to a submerged rock, could smash in the galley's bottom. Shallow water must therefore be avoided. The exact means by which depth was determined is not known for a certainty, but the crudest method available would be one of those methods used by the Egyptian's prehistoric ancestors, probably the weighted-line principle.

The weighted-line method certainly was being used some 2500 years later. According to a modern translation of Herodotus'[5] (484?-425? B.C.) writings the Greeks "cast the lead" and measured the depth of water in terms of a fixed standards of length.[6] As we will see later, the use of a standard of length with the weighted line was the only improvement of consequence from the days of the Stone Age down to the nineteenth century.

During Biblical times a hand-held, weighted line probably was used. Paul, being taken to Italy, observed that the seamen approached the land cautiously and sounded the bottom twice. The first sounding indicated twenty fathoms of water, the second, fifteen fathoms. On taking the second, the seamen anchored the ship, fearing that, if they approached closer to an unfamiliar coastline, the ship might strike a rock.[7] Without going into the question of the true length of the Biblical "fathom," we may be virtually certain that, in order to be safe from the rocks and shoals close to shore, the seamen anchored in water too deep to be sounded with a pole. Therefore they must have used a weighted line.

The difficulty of finding any comments on the art of sounding in literature earlier than the nineteenth century leads us almost to assume that there was no interest in the art until that time. Having existed in its crude form for countless generations, perhaps it was taken for granted and looked upon as something that sailors did but which was not worth improving, nor even worth writing about.

Certainly there were no improvements made, for to this very day the lead-line is used extensively all over the world for shallow-water sounding. Even on modern men-of-war, it is used to supplement the electronic equipment. Although basically unimproved, it is considered quite important. Its importance is reflected in U.S. Naval Regulations, which require the use of the hand lead when entering and when leaving port, or when approaching an anchorage, a shoal, or a rock. It is used especially when a slight drift must be de-

tected instantly, as when approaching an anchorage in shallow water.[8]

We are all a least vaguely familiar with man's experiences on the sea before the nineteenth century. We have read of scores of stout-hearted ship commanders who explored vast areas of ocean, discovering and plotting islands and continents as they explored. Through their exploration, these seafaring men had developed a moderate knowledge of the ocean; passed down in an unbroken chain from generation to generation and added to slightly from time to time, this knowledge had grown to significant proportions in some respects. During the nineteenth century, however, still more knowledge of the ocean came to be urgently required. Sea transport on a world-wide basis had been increasing steadily for years, and had, by the nineteenth century, attained considerable magnitude and unquestioned importance. Along with other oceanographic information required was a more comprehensive knowledge of ocean depth. Mariners and oceanographers, working on problems of weather, had learned that the contour of the ocean floor had a profound effect on the temperature of the water and on currents, and therefore on the weather.[9] Moreover, the successes of Morse's telegraph over land inspired audacious engineers to thoughts of telegraph from one land mass to another under the sea. By 1850 scores of marine cables were in successful use over short distances in many parts of the world,[10] and a cable to cross the Atlantic Ocean and connect the New World with the Old was being planned.[11] More information on depths of the ocean along the prospective cable routes was needed, for cable-laying required an accurate knowledge of depth, character of bottom (for assurance that the cable would not be worn badly by rubbing on sharp rocks), and currents at the bottom of the sea along the prospective cable routes.[12] These new interests in the ocean's floor furthered the art of deep sea sounding and brought modern intelligence to bear on methods by which the required information could be obtained.[13]

In the interests of providing the necessary oceanographic information, hydrographers made many long, tiresome and expensive voyages. Their vessels were the old sailing ships of the day, cumbersome and uncomfortable. Many of the hydrographic cruises lasted for years, and were punctuated with hardships, danger and frustration.

Nor did the sounding equipment available during the 1850's detract from the hardships and frustration. No improvements had been made in the methods of sounding. A man still dropped a weighted line overboard, letting the weight slip to the bottom and then hauling it up by hand, if the water was not too deep. Before 1773, if any efforts at all were made to sound the bottom of the sea they were unsuccessful, for the earliest genuine deep-sea sounding was recorded in that year. Captain Phipps had all the hand sounding lines on board his vessel spliced together. After attaching a weight of 150 pounds to the line, crewmen dropped the weight overboard, and payed out nearly a mile of rope before the weight struck bottom.[14] Then they had to haul it all in. By 1850, the principle used was not quite as bad as that, but it was almost as bad. By 1850 the men were employing light twine instead of rope.

If we think about it a while, we will not belittle the transition between rope and light twine. Although the improvement may seem simple-minded at first, actually it becomes a tremendous stride in the art of deep sea sounding when judged in the light of three thousand years of no improvement at all. That one improvement was the brain child of a U.S. Navy captain. Captain (then Lieutenant) Matthew Fontaine Maury,

U.S.N., (1806-1873) probably the greatest individual hydrographer in the United States during the nineteenth century and a powerful exponent of the science of hydrography, realizing the importance of gaining knowledge of the depths of the ocean proper, introduced a system for deep sea sounding which could be followed by almost any seafaring man worthy of the title. This system was extremely crude by present-day standards. But it was nevertheless a vast improvement, and did in fact make possible a hitherto impossible function: Using Captain Maury's system with patience and emotional fortitude, it was possible to sound depths to about 3000 fathoms. Captain Maury's equipment consisted of a ball or skein of strong twine and a cannon shot for a weight. Dropped over the side, the weight bore the twine downward, as had been the practice for thousands of years. But the good captain introduced certain refinements. First of all, he established specifications for the twine used. It should bear a weight of 20 to 30 pounds, he said, should have about the same specific gravity as seawater, should be a smooth kind of twine, and should be waxed or oiled. Prepared for a sounding, the twine should be marked every 100 fathoms with silk thread tied tightly around it. Every thousand fathoms should be coded with a different colored thread, the 100-fathom marks corresponding. The cannon shot should not be just tied on; rather, it should be placed in a sling made of canvas, and the sling fastened to the twine. When dropped overboard, the shot bore the end of the twine downward. When the shot struck bottom, the line was broken and the length of line lost, presumably being equal to the depth of water, was recorded. The moment at which the cannon shot struck bottom was indicated by a sudden slackening in the rate at which the twine was being payed out.[15]

As one may well expect, there were some successes with Captain Maury's method, and many failures. The successes may be attributed more to dogged perseverance and the high state of discipline among seafaring men than to perfection of the system in use. The failures were due for the most part to defective twine, weather conditions, and to difficulties experienced in the handling of the cumbersome sailing vessels. Some failures were probably due to the human factor: jerking of the line, tying of insecure knots, making of errors of measurement, and possibly others.

For details concerning the use of Captain Maury's cannon shot and twine method of deep sea sounding, we may look to the USS *Albany* and to the USBrig *Dolphin* which, among many other vessels, made extensive cruises in search of hydrographic data of all sorts. Writing in the official report of the *Albany's* cruise of 1850, Lieutenant William Rodgers Taylor expressed his feelings of disappointment and of hope: "We lost six shot in attempting to sound today, owing to the heavy swell, which caused the line to snap when the ship rose abaft. We then tried a bar of iron . . . which descended more rapidly than the shot; but the line failed and snapped . . . [we then] resorted to a thirteen-pound lead, and got bottom [1625 fathoms] . . . I set the drift at about one mile, from which you can easily calculate the perpendicular depth . . ." Later on, he added: "The experiments of today have cast a doubt over the former soundings, and now I am uncertain whether we ever obtained bottom . . ." In spite of ideal weather for sounding, he had obtained contradictory and confusing results. However, he added a ray of hope: "I am satisfied of the entire practicability of this mode of sounding," he said, "if you can get us *good* line; by good, I mean of *equal strength*. . . ."[16] Under similar circumstances, the *Dolphin*, in 1853, sounded to 3575 fathoms. In preparing for the cruise, the *Dolphin* took on a total of 235,000 fathoms of fishing line,

apparently expecting to use (or lose) a considerable quantity during the long months ahead. And the *Dolphin* did expend a large quantity of the twine. Several hundred soundings were made and recorded, ranging from a few fathoms to the maximum mentioned above. And although there were frequent references to the lines parting short of 1000 fathoms, many soundings were made at depths greater than 2000 fathoms.[17]

The seafaring man, after having carefully prepared several thousand fathoms of twine in accordance with Captain Maury's specifications, was not entirely willing to waste it. Probably with this in mind, another U.S. Navy officer improved on Captain Maury's method. Midshipman J. M. Brooke, in 1854, invented a means by which the cannon shot could be released when it hit the bottom. By releasing the cannon shot, crewmen could reel in the marked twine and use it again.[18, 19]

Parenthetically, about this same time a naval officer of another country gave us a good insight into the general ignorance of the sea and of oceanography suffered—or perhaps enjoyed—by some seafaring men of the era under investigation. This officer wrote a book lambasting the methods being employed in laying the first trans-Atlantic submarine cable in 1857. Throughout his book he scoffed at the idea of sounding the Atlantic along the prospective cable route, for, he said, the cable would not weigh enough to sink deeper than 200 fathoms, at which depth the density of water would equal that of the cable and the cable would remain fixed in depth, neither sinking nor rising. "Having displaced its specific gravity by descent," he avowed, "[it] would be equilibriated, or afloat." He laid claim to proof that a cannon would not sink to the bottom in deep water, and seriously—and earnestly—questioned all soundings below 1½ miles.[20] We know today that pressure in the ocean is a function of depth, but that water, being almost incompressible, has almost the same density at the surface that it has on the ocean floor. Knowing this, we may well wonder what our friend's considered opinion was on the subject of rocks and rubble. Did those, too, float at various depths depending on their densities?

In spite of the misapprehensions of some of the people of that era, the subject of sounding, of evergrowing importance, attracted many fine minds to its problems. For the next improvement of real consequence, we look to Great Britain and to the world-famous Scottish physicist, Lord Kelvin, then Sir William Thomson. Again, the improvement in basic method seems slight, the total system seems crude, and we wonder why it was not done earlier. But, as in the case of Captain Maury's improvements of a decade earlier, results were obtained with the new equipment which were not previously possible. Sir William used steel wire instead of twine, and designed a kind of machine to handle the wire.

The apparatus was officially named the Sir William Thomson's Deep Sea Sounding Machine. In its earliest form the Thomson machine consisted of a wooden rack mounting a wheel and a drum. On the drum were wound thousands of feet of slender but strong steel wire. No automatic means of hauling in the wire were available. An "endless rope" was manned by six men, three pulling the upper member toward the pulley wheel, and three the lower member toward the drum in back-breaking labor. No exact method was known for measuring the length of wire reaching to the ocean floor. In the words of the official instructions for operating the sounding gear, "The wire comes in different lengths, and as it is spliced it should be carefully measured, and the number of fathoms between the splices and the number of revolutions indicated by the counter between the splices, as

also the corresponding gain in fathoms should be noted in a book for future reference. . . . With this table, knowing the length of the stray line and the height of the reel above the surface of the water, it is easy to calculate the depth."[21] I question the word "easy." It appears to me that one would need to call in Sir William himself to calculate depth after the lead reached bottom! Further, limitations in the equipment were severe. Sounding operations using it were time-consuming; the cumbersome vessel had to be kept virtually stationary over the wire and sinker; and for all of this, the measurement of depth was of questionable accuracy, for the wire did not necessarily go straight down, but described a curve of unknown coordinates depending on ship motion, currents, and depth. But, compensating for these disadvantages, there was one very great advantage that the Thomson machine held over Captain Maury's scheme: with a crude sampling cup attached to its sinker, the Thomson machine could bring up a sample of the bottom.

Judging the equipment in its entirety by the good that was accomplished with it, one can plainly see that Lord Kelvin did indeed contribute a great deal to the art of sounding and the science of hydrography. Among the ships of the day putting out to sea on hydrographic cruises and fitted with the Thomson equipment were the HMS *Challenger* and the USS *Tuscarora*. The *Challenger's* cruise, commencing in 1873 and ending 1876, resulted in the recording of invaluable data about the Antarctic Ocean, Australia, New Zealand, the Philippines, China waters, and elsewhere in the Pacific and Atlantic oceans. Thousands of soundings were made, and great contributions made to geography and oceanography.[22] The *Tuscarora's* cruise was not so spectacular, but much valuable information was collected.[23]

At a later date, improvements in the Thomson rig incorporated a steam engine, which was employed in the reeling-in operations. Other improvements included a better reel and accumulator. These were incorporated in the first Sigsbee Improved Sir William Thomson's Deep Sea Sounding Machine. This machine could not lay claim to deeper soundings, but only to more dependable and easier operation.

Among the first vessels to employ the Sigsbee improvements was the steamer USS *Enterprise*. In spite of many handicaps, the *Enterprise*, on her cruise around the world between 1883 and 1886, took many hundreds of careful soundings, the deepest being rather deep: 4529 fathoms, a little more than five miles. From this depth a sample of the bottom was brought to the surface. These soundings were not made without preparation. In order to prepare for a sounding, the sails had to be furled and the smokepipe raised, and the ship's boilers had to be fired for two hours. Those things had to be done before the vessel could keep her position over the sounding wire. Each cast thus required hours to complete, cost half a ton of coal plus the wood required to start the fires in the boilers. And, of course, there were the usual accidents; breakage of the drum, loss of a specimen cup, parting of the wire at a splice or breaking altogether, and breakage of a drive belt were all mentioned in the official report. The headaches and heartbreaks did not go unrewarded, however. The *Enterprise* found two submarine peaks in the South Atlantic Ocean and an extensive sand bank several hundred miles from the coast of South America, and in addition made other discoveries.[24]

What kind of sounding equipment was used during World War I? You guessed it: Thomson's equipment, but further improved. A better system was

known, but little used. We will get to that later. By the time of World War I, the mechanical parts of the Thomson machine were more rugged and dependable. In addition, there was a dial to measure the amount of wire payed out, and a number of ingenious devices to bring up bottom samples. The most significant improvement of all, however, was a more exact method for determining the depth of water, a method depending on a physical property of the water itself. A glass tube, open at one end and closed at the other, and contained in a metal cylinder, was lowered open-end downward with the sinker. As the depth increased, the water pressure increased, air trapped in the glass tube was compressed, and seawater rose in the glass tube. The inside of the glass tube, treated with a chemical, changed color when wet, and, when hauled to the surface, left a positive record of the actual depth to which the tube had been lowered, a record which was independent of the amount of wire payed out.[25] This principle, too, was an innovation of Lord Kelvin.[26]

The Sigsbee sounding apparatus was based on the same principles as the Thomson equipment. By 1919, the only resemblance to Thomson's machine lay in the broad principles of paying out a weighted wire and determining depth by the high water mark on a thin glass tube. During the early 1920's an electric motor replaced the steam engine for reeling-in operations, with added dependability. The Sigsbee equipment in general was sturdier and more compact. Moreover, sinkers, specimen cups, and thermometers all showed improvements over earlier versions.[27]

Today, a characteristic machine for sounding with a weighted wire is the Tanner Blish machine. The many little refinements incorporated in this and in other modern machines have been brought about more by the general improvement in manufacturing techniques and proficiency in mechanical engineering than by any sweeping changes in basic principle.[28] Functionally, wire sounding equipment has changed in that its prime purpose today is not to determine depth, but to determine temperatures at great depths and to obtain samples of the ocean bottom. It follows that the machines should be designed more with those functions in mind than merely sounding. And that is true; today, with the weight of the paraphernalia used in bottom sampling and temperature measuring greatly increased, a slender steel wire is no longer used. Instead of the wire, a specially made hydrographic cable is used, which may have a diameter of 5/32 inch. Several thousand fathoms of cable of such size naturally require a larger drum and a stronger winch.[29]

If the weighted-wire method of sounding is no longer used, what has taken its place? What was the earth-shaking event which caused a radical departure in basic methods handed down from our forefathers of the Stone Age? These questions can be answered easily. But first let us determine why a radical departure was desirable. First of all was an economic reason. Even the best mechanical method was slow and costly. It was costly because it was slow. The sounding vessel had to stop completely or at least slow its speed for every sounding, and if the water were over 100 fathoms deep, the cast took hours to complete and cost a prohibitive amount of money. As a result, deep water areas were not sounded adequately, and many important submarine configurations were delineated poorly or not at all. Navigational charts, therefore, were rather inadequate insofar as depth of ocean was concerned.[30] Actually, although the number of soundings in depths less than a few hundred fathoms accumulated rapidly during the nineteenth century, by 1895 there existed only about 7000 soundings from depths greater than 1000 fathoms, and

of these only about 550 were from depths greater than 3000 fathoms.[31] A second reason why the equipment needed complete and utter revision was that no conceivable weighted-wire method could disclose depth to a high degree of accuracy. The best modern equipment of that sort in use today is subject to inaccuracies and failures.[32]

The earth-shaking event which finally guided man's thinking into proper channels and led him to a good method of sounding was the *Titanic* disaster in 1912. You may recall reading that the SS *Titanic,* then the finest passenger ship afloat, struck an iceberg on her maiden voyage across the Atlantic Ocean, and sank with terrible loss of life. Yet the *Titanic* was built and believed to be unsinkable, to be iceberg-proof. Apparently, then, it was not possible to build an unsinkable ship. So what could be done to reduce the iceberg hazard?

Professor Reginald Fessenden, an American, had an answer. He built a device to make sound under the water, a kind of loudspeaker mounted in the hull of the ship. And he mounted a microphone, or hydrophone, in the hull to hear noise coming from the water. He proposed to make a noise of short duration, a pulse of sound, in the water, then listen for an echo from an iceberg. Certainly his method was justifiable, for shipmasters had long been sounding a horn and listening for the echo through the air. And it was especially justifiable in that he discovered that he could determine the depth of water under the vessel by measuring the time interval required for the sound to reach bottom and bounce back.[33]

Professor Fessenden's early equipment had the serious drawback that the oscillator was keyed by hand and the time interval measured with a stopwatch calibrated in fathoms. Obviously such a system, accurate enough for deep soundings, was not dependable enough for use where the water was shallow and the time interval only a fraction of a second or so. Sound, traveling about 4800 feet per second, could find bottom at 2400 feet, or 400 fathoms, and bounce back 2400 feet to the ship, all in one second. Accordingly, some automatic keying device was required, and a faster method of measuring the time interval. Doctor Harvey C. Hayes, of U.S. Naval Research Laboratory, provided just that. By a clever use of a cam and disc on an electric motor, Dr. Hayes keyed Prof. Fessenden's oscillator automatically and at the same time read the depth directly from a scale. By listening to the returning echo with one ear and the following outgoing pulse with the other, he was able to send out one short pulse of sound at the same instant the echo from the previous pulse returned. A dial, synchronized with the keyer adjustment, indicated the amount of displacement of the cam, and therefore the depth in fathoms. This equipment established itself during experiments on the USS *Stewart,* in 1922. Participating in the experiments was young Philip T. Russel, of the Bureau of Engineering, U.S. Navy. Mr. Russel, later dissatisfied with the equipment because of the shallow limit of 400 fathoms obtainable, devised and patented an improvement which enabled the operator to obtain soundings in 80 fathoms of water.[34] Other engineers worked on the same problem. Some results were good, some were not. In general the sonic depthfinder was not yet adequate.

Shipmasters were still not satisfied with the equipment provided for regular and repeated use close to shore where the water not not very deep. The shallow limit of 80 fathoms was still too deep, they said, and besides, the "short" pulse of outgoing sound from the Fessenden oscillator was so long that reverberations in the water masked the returning echo in shallow water and cast doubts on the accuracy of the

soundings. A faster-working apparatus, making an extremely short pulse of sound in the water, was needed.

The "impact oscillator" was the answer to the new problem. A typical equipment of this type was the British Shallow Water Mark II. American equipments were developed along the same general principles. In the British Mark II equipment, the sound through the water was produced by a blow struck by a spring-driven hammer on a diaphragm in the ship's hull. A hydrophone detected the echo from the bottom. A keying device, synchronized with a scale calibrated in fathoms, triggered each hammer blow by an electrical impulse. The keyer also prevented the operator from hearing the returning echo unless the keyer was properly adjusted. To make a sounding, therefore, the operator had only to adjust the keyer with a crank until he could hear the return signal, and read the depth from the scale.[35]

The impact oscillator had two drawbacks, one of them in common with the Fessenden oscillator. The very nature of the source of sound from the impact oscillator limited the use of that principle to shallow water for the sound was not carried great distances. Further, both the impact oscillator and the Fessenden oscillator could be heard in all directions through the water, and disturbed the peace on board the ship as well. The true requirement seemed impossible to provide. What was needed was a powerful sound source which did not make any noise! Impossible as the requirements may have seemed, they were met by modern science and engineering. A device was developed which was able to put enough acoustic energy into the water to sound a depth of several miles—yet not be heard by a technician or other observer ten feet away. This was possible because the frequency of the sound used was beyond the upper limit of audibility of the human ear. It was still sound, in the technical sense; it could travel through the water, bounce off the bottom, travel back to the ship and be detected. But it could not be "heard" without instruments to convert it to audible sound. Because it could not be heard without unique equipment, it was not "noisy," in the usual sense, neither would it (at that time) disclose the vessel's position to an enemy submarine.

An important advantage accruing to the use of ultrasonics, as such high-frequency sound as that is now termed, was the fact that the sound could be directed downward in a beam, rather than be spread uniformly in all direction in the manner of the Fessenden oscillator and the impact oscillator. Because a greater percentage of the available acoustic energy was directed in a useful direction, the total amount of energy required for sounding was reduced.

Developed in secret by the U.S. Navy during the early 1930's, this new kind of sounding apparatus was called the Navy Models NG and NM Fathometer Equipment. Basically, it consisted of a transmitter mounted in the hull and containing vibrating Rochelle salt crystals, a driver to provide the necessary high-frequency alternating current, and a receiver-indicator to key the driver, to convert the returning echo to an audible signal, and to measure the time interval between the outgoing and echo pulses. Depth in fathoms was read directly from a circular scale at the point where the returning signal flashed a red light. That was the method used for shallow water and for water at ordinary ocean depths. For extremely great depths, the automatic keyer could be disengaged and the driver keyed manually.[36]

It was with equipment of this kind that the USS *Ramapo* obtained a sounding in the Japan Trough (a particu-

larly deep part of the Pacific Ocean) of 5770 fathoms, or about six and one-half miles.[37]

A typical ultrasonic echo sounding equipment of today has much in common with the *Ramapo's* equipment of the 1930's: hull-mounted transducer, or transmitter; driver, the source of energy; and receiver-indicator, usually mounted on the bridge or in the chart house of the vessel. Today there are some additions: a recorder to make a permanent record of the depth along the track, or route of the vessel, and perhaps an alarm to warn the navigator or conning officer of shallow water. Taken as a whole, it is a masterpiece of human ingenuity and precision workmanship. It can be operated by any intelligent person after only a few minutes of instruction, and its almost universal employment on large seagoing vessels of all descriptions is a testimonial on its ruggedness and dependability. It may be used equally well in shallow water or in the deepest, and makes few demands on its operating personnel beyond that a switch be thrown and a dial or paper record observed. With equipment of that sort, it is no more difficult to sound the ocean's depths than a harbor's shallows; and with naval and commercial vessels making systematic records of depth wherever they go and forwarding them to hydrographic offices, soundings of the deep sea are accumulating faster than they can be plotted.

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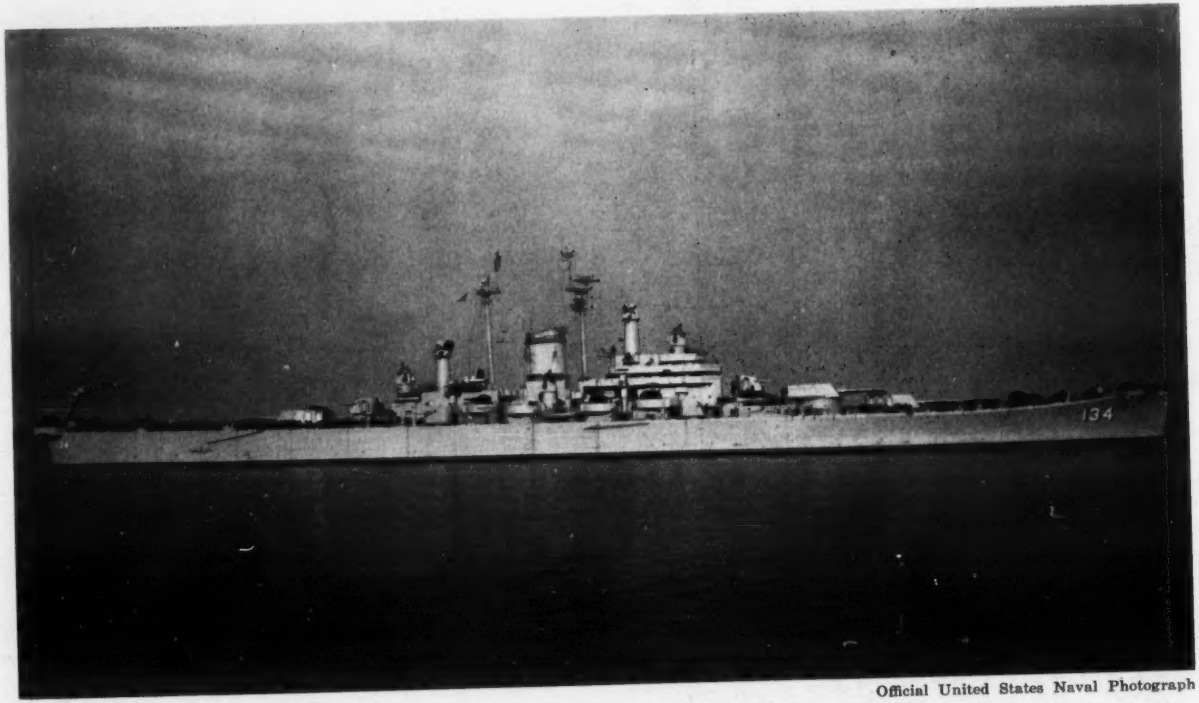

Official United States Naval Photograph

THE THRUST DEDUCTION

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INTRODUCTION

For many decades the interaction between the ship and the screw propeller has been successfully studied by experimental methods. By introducing the concepts of wake and thrust deduction the first step of any scientific approach has been performed, i.e., fundamental concepts have been created upon which a further theoretical development can be based. In our case, however, this scientific development which essentially means an explanation of observed effects by hydrodynamic laws has been rather slow. This applies especially to the problem of thrust deduction which for a long time was considered with a mystical awe. Theoretical investigations by Fresenius [18] and Horn [5] and beautiful experiments by Eggert and Janes [30] contributed much to a clarification of our problem but a sound hydodynamic theory of the phenomena involved was not worked out until 1938 by Dickmann.

Dickmann's first memoir [2] which deserves the predicate of a classical investigation has been reviewed and supplemented by experimental results by Schoenherr and Aquino [7]. Otherwise Dickmann's work on the subject, which in 1939 was extended by another publication of more practical character [1], has not found the merited acknowledgment in this country. Later other authors abroad presented further contributions to the subject.

Because of the basic importance of the problem it was thought appropriate to give in this paper a simple description of the theoretical methods used in research of thrust deduction and to sketch briefly the state of knowledge so far reached.

Although a lot of experimental data are available a proper understanding of the subject cannot be reached without elements of theory. In what follows it is assumed that the reader is familiar

with the basic presentation of the subject as given for instance by references [35] and [36].

The state of our scientific knowledge may be summarized as follows: Dickmann has succeeded in elucidating the main features of the problem. Later contributions by other authors have not added essential ideas; however, experimental investigations indicate that reliable quantitative agreement between theory and measurements has not yet been reached even in some basic cases and that some important effects cannot yet be explained in the light of the present theory. Thus, continued endeavors will be necessary to close the gap mentioned. Further, so far no theoretical investigation exists dealing with the ship, propeller and rudder combined.

The main idea of modern investigations on the subject consists in describing the flow around the hull and the propeller by an appropriate choice of singularities (images) (Part I). Once these generating images (sources and sinks, doublets) are known, it is a matter of technique (although sometimes tedious technique) to compute the forces resulting from the mutual interaction between the hull and the propeller. This is done for uniform motions which alone will be considered here by Lagally's theorem. In Part II we give a short explanation of this theorem which proves to be a powerful tool in hydrodynamic research.

The whole field of Theoretical Naval Architecture dealing with the motions of ships and other floating bodies is now widely based on the study of some hydrodynamic elements or systems of singularities and the combinations of such elements. Solutions obtained for the wave resistance of ships can be immediately applied to the present subject; the knowledge of velocity potentials involved admits further solutions for vertical forces and other items which are important in the theory of directional stability and seaworthiness.

Part III contains a brief survey of wake phenomena, Part IV the analysis of the interdependence between wake and thrust deduction following Dickmann, and Part V presents a discussion of various practical problems connected with our subject.

I. REPRESENTATION OF THE HULL AND THE PROPELLER BY HYDRODYNAMIC SINGULARITIES

The Hull. Powerful mathematical methods have been developed to treat two dimensional plane motions of fluids. Unfortunately the interesting and otherwise important solutions so obtained are not too helpful in Theoretical Naval Architecture since the fluid motion is here essentially three dimensional. There exist of course well known results for simple three dimensional bodies, but the shape of the ship hull is so complicated that these results furnish only some general ideas and analogies when dealing with our problem.

As mentioned in the introduction the present state of knowledge forces us to translate, so to speak, the actual hull form into an artificial hydrodynamic language, or otherwise expressed, to represent the bodies by suitable singularities for which the flow in a non-viscous flow can be calculated. The problem is severely complicated by the fact that the ship moves at the free surface. Thus, at present we can obtain only some rough approximations which, however, prove to be very efficient when solving practical problems.

The appropriate singularities needed in theoretical naval architecture are mainly sources and sinks or doublets,*

* Obviously this remark does not apply to propeller theory.

while in applied aerodynamics emphasis is laid rather on vortices. This shift in the importance of basic elements and still more the presence of the free surface in our problems are responsible for the fact that the knowledge of classical aerodynamics is necessary but by far not sufficient when dealing with hydrodynamics of ships.

Because of the complex character of our problem it is advisable to start with the simplest case of wholly submerged bodies of revolution.

The generation of bodies of revolution by line sources and sinks distributed over an axis in a uniform flow is well known. Descriptions of the method involved can be found in any text book on hydrodynamics. The simplest examples are: (1) Rankine's ovoid, generated by a point source and sink; and (2) the most important *ovary spheroid* corresponding to a source-sink line

$$\sigma(x) = \sigma_0 \frac{x}{l} = \sigma_0 \xi \qquad (1)$$

See Fig. 1 and 2. The origin is located in the middle of the body.

To avoid confusion we shall distinguish between the output of a point source Q and its strength Σ. The concept strength has been introduced as abbreviation from considerations of potential theory

$$Q = 4\pi\Sigma$$

with the potential $\varphi = \frac{Q}{4\pi r} = \frac{\Sigma}{r}$ (2)

q, σ, with $q = 4\pi\sigma$, are the corresponding values for line and

$$q^*,\ \sigma^* \text{ with } q^* = 4\pi\sigma^*$$

for surface sources. Physically the *output* Q is the more important item, since it equals the flux per second generated by the source; its dimension is Vol/sec.

FIG. 1—Image Systems for a Rankine's Ovoid

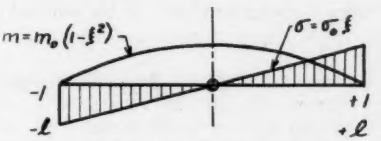

FIG. 2—Image Systems for a Prolate Spheroid

For a line distribution, q means the flux per second per unit length (dimension Vol/length × sec.), for a surface distribution, q* has the dimension of a velocity.

Alternatively, doublet distributions are used. We define these distributions by the moment of output m(x) or the moment of strength $\mu(x)$

where $m(x) = 4\pi\mu(x)$

The well known relation

$$\mu(x) = \int_{l}^{x} \sigma(x)\, dx \qquad (3)$$

connects the equations of the source line and doublet line distribution. Thus the moment of the doublet m(x) at any point gives the total flux up to this point. For Rankine's ovoid, Fig. 1, the distribution is a horizontal line

$$m(x) = 4\pi\mu(x) = \text{const}$$

and for the prolate spheroid, Figure 2, a simple parabola

$$m(x) = m_0 [1 - (x/l)^2] = (1 - \xi^2)\, m_0 \qquad (4)$$

In our case, the representation by doublets does not furnish any new result, but it has some practical advantages when dealing with very elongated bodies

since for large $\frac{l}{b} = \frac{L}{D}$

$$m(x) \sim A(x)$$

the distribution $m(x)$ is approximately affine (similar in trend) to the sectional area curve of the body $A(x)$. The maximum section of the body A_0 is connected with the maximum ordinate of the doublet curve m_0 by the approximate relation

$$m_0 = 4\pi\mu_0 = A_0 v_0 \qquad (5)$$

where v_0 = velocity of stream or speed of advance.

The total moment of the doublet distribution

$$M = \int_{-l}^{+l} m(x)\, dx \cong v_0 \int_{-l}^{+l} A(x)\, dx = V v_0 \qquad (6)$$

is proportional to the volume; it can be shown that $M = V v_0 (1 + K_x)$ where K_x is the added mass factor of the body in the direction of the x-axis.

To represent a moving ship we should distribute sources and sinks over a surface or a volume; but the simplest method is to use the center plane (x z plane). This procedure is very popular when dealing with resistance problems. The shape of the resulting bodies is, however, not known except for a general ellipsoid which can be created by a suitable distribution of doublets over the focal conic [4].

Altho we do not know exactly what actual hull form corresponds to a given intensity of doublets we can get an approximate idea from a relation similar to (5), stating affinity between the form of the ship sections and the distribution of doublets over these sections. As soon as the singularities are known the theorem of *Lagally* [9, 10], mentioned later, enables us to calculate hydrodynamical forces experienced by the ship moving uniformly under given conditions in a frictionless fluid.

The propeller. It is well known that from a hydrodynamical viewpoint the screw propeller may be replaced by a system of vortices. For our present purpose, which is to study the interaction between ship and screw, a much simpler mechanical model may be substituted; leaving the slipstream outside the scope of our considerations, we replace the flow due to the propeller by a sink located at the propeller center, whose "input" depends on the final slipstream velocity u and the disc area A.

$$Q = A \quad v_0 s' \qquad (8)$$

s' is the theoretical slip ratio $\frac{u}{v_0}$

The next step is to assume a *uniform distribution* of sinks q_0 over the disc.

$$Q = A\, q_0 \qquad q_0 = v_0\, s' \qquad (9)$$

and finally, a more general solution is given by

$$q = \text{const} = q(y, z)$$

$$Q = \int q\, dA \qquad (10)$$

Experiments prove a remarkable agreement with some results deduced from our simple assumptions, as has been pointed out by Dickmann.

II. LAGALLY'S THEOREM

The theory of aerodynamical lift, and therefore, large parts of aerodynamics, are based on the Kutta-Joukovsky theorem

$$L_1 = \rho v \Gamma \qquad (11)$$

Here the principal concept is the vortex with a given circulation.

In Theoretical Naval Architecture, the prevailing singularity is the source (sink) characterized by the output Q.

For steady motion a formula exists due to Lagally which is analogous to Kutta-Joukovsky's; it links the force F experienced by a source (sink) with the *speed* of flow at the location of the singularity v and the *output* Q, [9, 10, 11, 12]

$$F = -\rho v Q \qquad (12)$$

In [11] this formula is deduced for a *source* in a uniform stream v_o by applying the momentum theorem, Figure 3.

As controlling surfaces assume two vertical planes and a very long cylinder, in the limit, the whole output of the source flows thru the curved sheet. Investigating the flow at the cylinder sheet we find the rate of change of momentum given by $\rho Q v_o$, Figure 3; the direction of the force is opposite to the direction of speed v_o, hence, we may write

$$F_{+Q} = -\rho v_o Q \qquad (13)$$

A *source is attracted by a uniform stream.* The result may be easily grasped from a physical reasoning; representing the source by a pipe discharging an amount of water Q into a uniform stream, we see at once that a jet is deflected rearwards; hence, a force in the opposite direction must arise. Figure 4.

A *sink is repelled by a uniform stream.*

$$F_{-Q} = +\rho v Q \qquad (14)$$

F_{-Q} is a *resistance.*

These interesting results can be generalized for any steady flow. The forces F_Q depend only on the value of the velocity field v at the locus of the singularities involved.

A proof of Lagally's theorem in a simple case follows immediately from potential theory. For two sources or two sinks the resulting forces are equal and opposite.

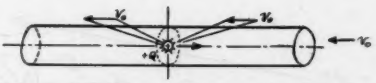

FIG. 3—Momentum Theorem Applied to a Source in a Uniform Stream

$$F_Q = -\rho \frac{Q_1 Q_2}{4\pi r^2} = -\rho Q_1 \frac{Q_2}{4\pi r^2} \qquad (15)$$

and mean attraction [13].

Formula (15) written as $-\rho \frac{Q_1 Q_2}{4\pi r^2}$ expresses Newton's or Coulomb's law; sources and sinks interact in a manner like electrostatic charges, with the important difference that singularities of *equal sign* attract, of *different sign repel* each other. On the other hand, Formula (15) written as $-\rho Q_1 \frac{Q_2}{4\pi r^2}$ can be interpreted as Lagally's formula with $v = \frac{Q_2}{4\pi r^2}$. Thus in some simple cases we may use Newton's formula as well as Lagally's, but the latter has the advantage of much higher generality.

These simple rules are a safe guide when dealing with the behavior of bodies in a divergent or convergent stream. However, it must be kept in mind that the shape of the bodies represented by source-sink combinations depends also on the outside flow.

Similar reasoning applies to vortices [12, 13].

We note a further theorem due to Lagally dealing with forces experienced

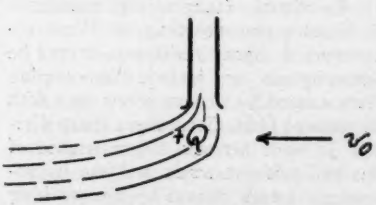

FIG. 4—The Model of a Source in a Uniform Stream

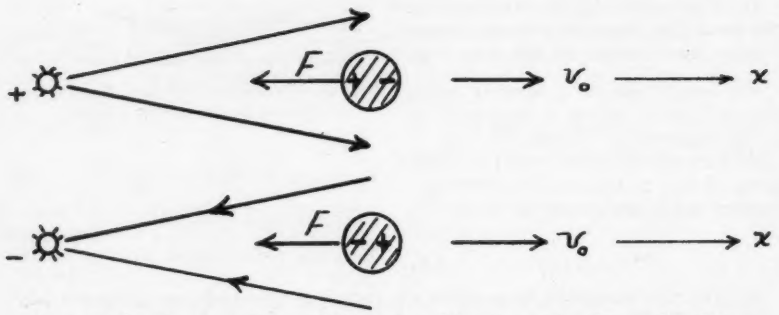

FIG. 5—Forces Experienced by a Cylinder in a Diverging and a Converging Stream

by a doublet [12] Figure 5.

$F = -\rho M \frac{\partial u}{\partial x}$ with M moment of the doublet (16).

By applying Lagally's theorem to a combination body of *revolution + sink (propeller)* in an unlimited uniform flow we obtain a simple expression for the thrust deduction force.

$$F = \frac{Q}{4\pi} \int_{-l}^{+l} \frac{q\ (x)\ dx}{r^2} \qquad (17)$$

$$r = a + l + x$$

where $Q = Av_o s'$ (8)

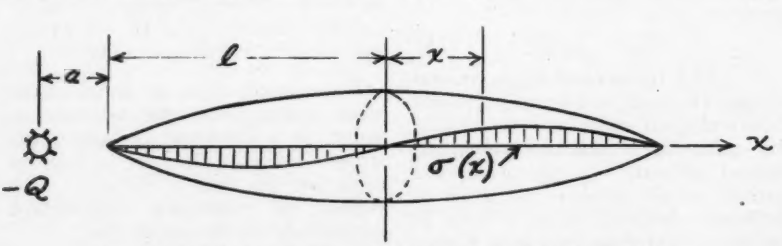

FIG. 6—Calculation of Thrust Deduction for a Body of Revolution

III. WAKE

When we consider the different "kinds" of ship resistance in calm water; 1. Frictional (tangential) resistance 2. Viscous pressure drag. 3. Wave resistance. 4. Spray resistance, it may be advantageous to include the suction force caused by a stern screw as a fifth component [16]. Generally a sharp division is made between the resistance of the hull without screw and the hydrodynamic forces caused by the working propeller; this division is legitimate, but involves an obvious danger which may arise (and really has arisen) when developing ship forms.

The nature of the interaction between hull and propeller, and concepts and definitions introduced are explained in *Schoenherr's* and *Aquino's* report [7] to which reference is made. The actual technical problem presents considerable difficulties.

The propeller works in a region of flow disturbed by the hull. Its action

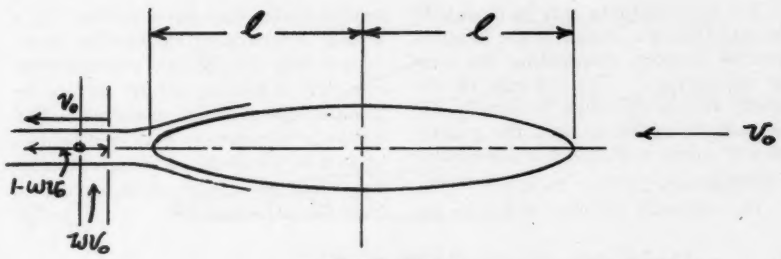

FIG. 7—Wake

causes a decrease of pressure on the stern and some increase in frictional resistance of the ship.

The wake speed (w v) is the speed of particles to which the hull has imparted a motion. Taylor's Wake Fraction w varies generally over a section representing the idealized propeller disc $w = w\ (y, z)$, but for evaluation of experiments some average values are used which can be arrived at in different ways.

The difference $\Delta R = T\text{-}R$ (18)

Thrust on propeller shaft—tow rope resistance, is known as suction force, thrust deduction force or resistance increase; $\frac{\Delta R}{T} = t$ is the thrust deduction (coefficient).

The wake velocity consists of 3 "components" characterized by the wake fractions:

a. potential (streamline) ..... w_p
b. wave ..... w_w
c. frictional (viscous) ..... w_f

The first notation is unlucky, as the wave wake can be derived from a potential; probably displacement wake is a better terminology.

$$w = w_p + w_w + w_f \qquad (19)$$

The concept "potential wake" or "displacement wake" is familiar from the study of motion of a body in an unlimited ideal fluid (without free surface): At the screw disc (near the stern) there is a high static pressure or low velocity relative to the hull, hence, a positive wake speed $w_p v$.

Studying waves produced by a ship, we conclude (the best way is to treat it as a steady motion) that under a crest we get a positive wake, under a trough a negative; the speed wv_o may be easily calculated from the orbital motion $\frac{2\pi a}{T_w}$

a = wave amplitude, T_w = wave period.

The frictional wake corresponds to the resistance

$$R_f = \rho \int (v - v_f)\ v_f\ dA$$

where $v_f = w_f v$; (20)

the wake speed v_f means a loss of pressure head of about

$$\rho\, v_f\, (v - v_f/2)\ [1]. \qquad (21a)$$

The different components of wake influence each other so that each component is quite different from that value which it would attain when the other components disappear. This is particularly true for the influence of the viscous wake on the potential and wave wake [1].

Helmbold has proposed a procedure as to how to separate the values w_p and w_f [14]; the problem is quite important as the influence of w_p on the propulsive efficiency is opposed to that of w_f. The frictional wake influences deeply the displacement (potential) wake [1]; Helmbold's earlier proposal to measure the latter by reversing the towing direction does not lead, therefore, to a solution.

The frictional flow may be dealt with by introducing a change in the distribution of doublets determining the form of the stern [1]. The influence of viscosity on wave motion is equally important; it is known that the generation of waves at the stern is appreciably reduced.

The influence of wave wake on potential wake may be described by a change in generating singularities necessary to keep the shipform constant when our ship is floating on the surface instead of being deeply submerged. This influence is generally neglected because of lack of knowledge, although the neglect may cause appreciable errors at high Froude numbers.

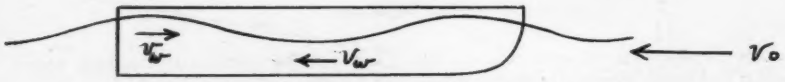

FIG. 8—Wave Wake

IV. THRUST DEDUCTION AND WAKE

The thrust deduction force Δ R can be calculated from differences in the *potential, wave* and *viscous* flow between the two conditions—hull with working screw and without screw. We distinguish potential $= t_p$, wave $= t_w$, and viscous $= t_f$ thrust deduction. The two latter components generally are very small. A negligible wave thrust deduction means that the generation of ship waves is only slightly influenced by a working propeller. Experiments made by Janes (TMB Report 453) support clearly this theoretical reasoning which at first does not seem to be obvious at all; it may fail in some limiting cases such as high loaded propellers.

The statement $t_f \cong 0$ means that the increase in viscous resistance all over the ship (stern parts forward of the screw, rudder in the race) is negligible or extremely small; it does not hold for old fashioned bad rudder and stern forms. Thus the main part of the thrust deduction appears to be due to the potential flow t_p. One should expect a good agreement between the suction force derived from Δ R = T-R and the force calculated from the difference of pressure values $\Delta p = p_1 - p_o$ over the afterbody

$$F = \int \Delta p \cos (n, x) \, d S$$

where p_1 corresponds to the condition hull + working propeller, p_o = hull without propeller.* Unfortunately, that is not the case: experiments made by Janes and at the Berlin Tank [17] yielded F $\cong$ 0.5 to 0.75 Δ R only. The reason for this discrepancy has not yet been explained; as mentioned before, friction is much too low to account for it. Since pressure measurements have been hitherto somewhat inaccurate we may hope to get better results with a better technique of experimenting, especially as high peaks of under-pressure may be responsible for a considerable part of the resulting pressure force. Even secondary effects must be observed. For instance, experiments made at the Berlin Tank indicate that a narrow slot between the propeller hub and stern tube flange may cause appreciable suction forces [17].

We have approximated the hydrodynamical effects of the propeller by a sink or system of sinks neglecting the rotational properties of the slipstream, since the tangential component of the

* n is the normal to the surface.

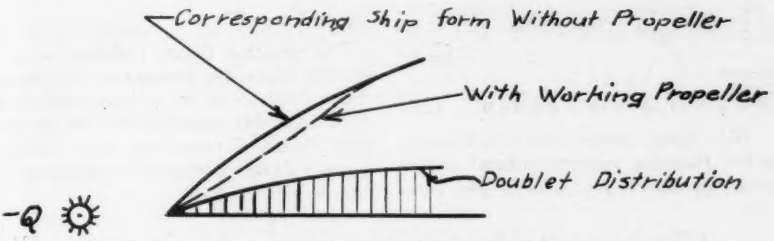

FIG. 9—Influence of a Working Propeller on the Body Form Due to a Given Doublet Distribution

velocity is created in the propeller space only. Some doubts may be expressed if this neglect can lead to errors; they may not be serious in the light of experiments made by *Aquino* and *Baker*.

It is somewhat laborious but not difficult to measure the wake behind a model without screw; we get the so-called *basic* wake. It has been proved by Helmbold [15] and Dickmann [1], that the *effective* wake, which is averaged by Froude's method and should be used when applying Lagally's formula, is somewhat different as:

a. The working propeller (sink) changes the shape of hull represented by a definite sink distribution—instead of the continued line we get the dashed line, Figure 9. To restore the original body we must add some doublets (or shift some sinks); this causes an increase in the potential wake.

b. The working propeller has a wave velocity field of its own, which reduces slightly the wave wake originated by the ship.

c. The suction of the propeller causes a narrowing of the frictional wake belt and a reduction of its mean value. Thus in principle, no exact agreement between measurements of the basic and effective wake can be expected as they really refer to different items.

Another important matter is the influence of the irregularity of the wake on the thrust distribution over the propeller. At points of high wake values the local density of thrust $\frac{\partial T}{\partial A}$ exceeds sensibly the mean value $\frac{T}{A}$; the distribution of sink intensity q over the disc is then very far from uniformity and a high increase in the suction force may result [1] following the reasoning developed in Part II.

We proceed now to establish a most important dependence between the potential wake (uniform distribution) and thrust.

Imagine that a wholly submerged body advances with a speed v_o through a non-viscous medium. The equivalent of the resistance force R is given by a tow-rope force applied from outside to the system. This force is counter-balanced by a part of the propeller thrust and must appear as the momentum of the propeller race.

We get, therefore, an expression connecting the tow-rope resistance R with the momentum of the slip stream. Far away from the propeller we have

$$R = \rho A_\infty (v_o + u)u \qquad (21)$$

where A_∞ is the cross section of the race far behind
u is the theoretical slip stream velocity.

Let the propeller work in a uniform wake w_p; the water volume per unit time passing through the propeller disc is

$$A\,[v_o\,(1-w_p)+u/2]=A_\infty \quad (v_o+u) \tag{22a}$$

hence

$$R=\rho\,A\,[v_o\,(1-w_p)+u/2]\,u; \tag{22}$$

We have anticipated *Dickmann's* proof that the velocity induced at the propeller disc is $u/2$ also in this complicated case [2].

The propeller thrust T cannot be calculated from the momentum imparted. Since there seems to be some confusion regarding this important point we repeat shortly a reasoning due to Dickmann. Using Bernouilli's equation it can be proved, that

$$T=\rho\,A\,(v_o+u/2)\,u=\rho\,Av_o^2\,(1+s'/2)\,s' \tag{23}$$

the thrust is independent of the potential wake w_p!

Putting $T\,(1-t_p)=R$ one obtains from (22) and (23)

$$\rho\,A\,(v_o+u/2)u(1-t_p)=\rho\,A[v_o(1-w_p)+u/2]u,$$

$$t_p=w_p\,\frac{2\,v_o}{2\,v_o+u}=w_p\,\frac{2}{2+s'} \tag{24}$$

The same result may be obtained by calculating

$t_pT=\Delta R$ from *Lagally's theorem*

$$R=\rho\,Q\,v_o w_p$$

with $Q=Av_os'$; hence, $\Delta R=$

$$\rho\,Av_os'\,v_o\,w_p=\rho\,Av_o^2w_ps' \tag{25}$$

leading to (24). Introducing the load coefficient

$$\tau_r=\frac{2T}{\rho\,v_o^2A},\ s'=-1+\sqrt{1+\tau} \tag{26}$$

we get further $t_p=w_p\,\dfrac{2}{1+\sqrt{1+\tau}}$

The *potential thrust deduction* t_p is proportional to the *potential uniform wake* and decreases with *increasing load coefficient.*

This is a most important result.

By introducing a resistance load coefficient

$$\tau_r=\frac{2\,R}{\rho\,v_o^2A}=(1-t_p)\tau$$

Dickmann gets for the propulsive coefficient

$$\eta_o=\frac{Rv_o}{Rv_o+\rho\,A\,[v_o\,(1-w_p)+u/2]\,u^2/2}=\frac{2}{2+s'}=$$

$$\frac{2}{1+w_p+\sqrt{(1-w_p)^2+\tau_r}} \tag{27}$$

This is again an important result: it proves that the positive potential wake is detrimental to efficiency, especially when τ_r is large while a negative w_p is advantageous. Thus, the high efficiency of *Kort* nozzles at high load coefficients τ_r can be explained: they create a strong negative w_p at the propeller disc.

Important calculations were made by Dickmann concerning the wave-making resistance of a propeller. [1, 2, 3] Representing the screw by a sink and using the expression for the velocity potential of the latter, he has shown that the resistance plotted as a function of a

Froude's number $\frac{v_o}{\sqrt{gh}}$ where h is the depth of immersion of the propeller axis, reaches a maximum at $\frac{v_o}{\sqrt{gh}} = 1,\ 2.$ This corresponds to a "common" Froude number $\frac{v_o}{\sqrt{gL}} = \frac{v_o}{\sqrt{gh}} \sqrt{\frac{h}{L}}$ which is regularly attained or exceeded by ships of medium or high speed. Even so the wave resistance of the propeller is normally small and has a considerable importance only by interference effects with the ship waves. When the propeller penetrates the surface the energy lost by creating waves may become more appreciable. For readers familiar with the theory of surface waves the theory of this part of Dickmann's work is especially recommended. Assuming a uniform wake w the propulsive efficiency becomes

$$\eta_o = \eta_{pr} \frac{1-t}{1-w} \qquad (28)$$

$$t = t_p + t_w + t_f \cong t_p$$

since t_w and t_f are very small

$$w = w_p + w_w + w_f \text{ (effective wake)} \qquad (29)$$

$$\eta_o = \eta_{pr} \frac{1-t_p}{1-w} \text{ approximately} \qquad (30)$$

the propeller efficiency corresponding to a rate of advance

$$J = \frac{v_o(1-w)}{DN}.$$

When dealing with a *non-uniform distribution* of wake, we consider the propeller as being composed of elementary propellers, for which calculations can be performed individually.

V. FURTHER REMARKS ON THRUST DEDUCTION

1. An important problem is the influence of *scale effect* on the *thrust deduction*, especially the relation between the scale effect of the model and the ship. It has been pointed out that the viscous thrust deduction is a small quantity; but it would be erroneous to conclude that no scale effect can exist. In principle such an influence can be expected as an indirect effect: we know that the thrust deduction is highly sensitive to the non-uniformity of wake (including the frictional wake), which of course is variable with Reynold's number; besides the frictional wake interferes in a different way with the potential wake on ship and model. We get the following conflicting tendencies:

a. Using dashed symbols for the model let us compare a ship with a model. Under normal conditions (smooth surface) the mean value of the frictional ship wake w_f is smaller than the frictional model wake w'_f; thus the potential wake of the ship w_p is less reduced by viscosity than the corresponding model wake w'_p or $w_p > w'_p$; hence, by formula (24) the potential thrust deduction $t_p > t'_p$. On the other hand, under the same conditions, the non-uniformity of the ship wake, especially some peaks in the velocity distribution, is lower than in the model; this influences the relation between t_p and t'_p in the opposite direction as before trying to make $t_p < t'_p$.

b. No estimates have been made so far as to the order of the two-mentioned influences. However, in the light of the preceding reasoning one can expect with some confidence that the thrust deduction of the ship does not differ appreciably from the corresponding value of larger models.

c. Investigations in the model range have not led to conclusive results. Experiments on model families made by *van Lammeren* [20] did not reveal any dependence of the thrust deduction on Reynolds number while *H. Voigt* has stated a drop of t with increasing model size [19].

d. *Van Lammeren* has roughened one of his models and has not found any influence on t compared with the smooth model at the same thrust [20].

Such experiments should be repeated with great care. It may be interesting to make the frictional wake of a model similar to the corresponding one of the ship by influencing the boundary layer of the model.

2. We mentioned a considerable gap between the measured "resistance augmentation" $\Delta R = T - R$ and the suction force computed from pressure measurements $F = \int \Delta p \cos(n, x)\, dS$ and found as the only explanation available today the inaccuracy of pressure measurements and the insufficient number of spots investigated which may lead to appreciable errors as Δp is the difference of readings; for instance the lack of orifices at the bossings in Janes' experiments is a grave objection to the validity of the final values. However, it is more difficult to explain why even with bodies of revolution the agreement between the two methods is not satisfactory, since here the pressure distribution is much more uniform. As a remedy one can suggest: increase in number of orifices, increase in accuracy of measurements, elimination of errors like the underpressure in slots, etc.

The uncertainty of the present state of knowledge leads to such artificial and improbable explanations as adopted by Weitbrecht [17]: he tries to bridge the gap between the two experimental results by arbitrarily assuming high additional frictional forces. Following Weitbrecht these are due to the sucking off of the boundary layer and the resulting increase in tangential stresses; but a rough estimate indicates that these effects can be secondary only. If, however, one does not succeed in explaining the difference stated even by wholly reliable pressure tests, the problem of tangential forces should be reconsidered, e.g., by testing a propeller behind a flat plate, etc.

The use of bodies of revolution as a preliminary step before investigating ship models is a merit of Weitbrecht's approach. Good agreement has been found between calculated and measured velocities around these bodies due to the propeller action.

3. Experiments should be performed for various speeds and load coefficients. Theory has succeeded in explaining that in the moored condition $t = t_o$ increases with increasing propeller load while for the advancing ship t decreases with increasing load coefficient. Especially interesting are measurements at the zero thrust point $T = O$ where the suction force is only due to the non-uniform distribution of thrust over the disc [1].

A formula proposed by Helmbold

$$t = \frac{t_o\, u/2 + v_o\, w_p}{v_o + u/2} \qquad (31)$$

valid for ideal fluid has been checked by Bassin [24]; it is suitable for experimental verification.

4. The thrust deduction of single screw ships is much higher than the corresponding one of bodies of revolution. Proposals have been made by Hogner and Kempf to produce a more uniform wake, for instance by tapering the after body into a body of revolution. [23] This proposal may be linked up with the writer's findings on some advantages connected with a stern bulb at higher speeds [16]. However following the present prevailing opinion on Hogner's suggestion expressed by *van Lammeren* in a contribution to [1] the increase of resistance of such forms outweighs the favorable influence on propulsion.

Contradictory solutions have been proposed even for elementary practical problems connected with our subject. *Van Lammeren* has suggested to decrease the diameter of the propeller of single screw ships with the purpose to

reduce somewhat the non-uniformity of wake; he claims a gain in efficiency. *Horn* and *Yamagata* on the other hand, have found an increase in the thrust deduction t with increasing number of revolutions of the propeller due to a reduction of diameter [33]. Probably a solution of this contradiction will be found by a closer investigation of the character of wake.

5. *Longitudinal position of the propeller.* Some experiments have been made to check the influence of a propeller position on the efficiency, for instance by *D. W. Taylor* [32], and by *van Lammeren* [20]. The latter stated a beneficial effect with increasing distance e of the propeller up to 2D. The matter is a rather complex one, as it includes:

a. decrease of t with increasing e (increasing propulsive efficiency).

b. decrease of w_p with increasing e (increasing efficiency).

c. nearly constant w_f.

d. changes of w_w which may be beneficial or detrimental to efficiency.

Contrary, however, to the findings of van Lammeren experiments made by *Yamagata* [1] and analyzed by *Dickmann* [1] indicate a drop of hull efficiency with increasing distance so that in any special case a careful investigation is needed.

6. Schoenherr and Aquino have developed empirical formulae for the wake and thrust deduction [7, 35].* Since they are based on the analysis of a large number of model data they deserve a careful study.

a. The formula proposed for the wake of single screw ships [7, 35] depends among other factors upon the vertical prismatic $C_v = \chi$; obviously it is preferable to use the value for the *afterbody* $\chi_A = C_{VA}$ only, as this coefficient describes fairly well the U or V shape of the run sections which influences decisively the distribution of the wake.

The magnitude of the total coefficient $\chi = C_V = \frac{1}{2} \quad (C_{VA} + C_{VF})$ depends upon the shape of the sections in the forebody expressed by $\chi_F = C_{VF}$, as much as upon $\chi_A = C_{VA}$, but variations of χ_F affect the wake in a different way by influencing primarily the wave pattern.

The Schoenherr formulas apply to the usual position of the screw relative to the ship. Such important items as the distance e and the Froude number do not appear. Finally, since the wake formula has been derived from model tests only, the question remains open as to how results may be extended to full size ships.

b. A simple formula

$$t = kw \qquad (32)$$

links the thrust deduction of single screw ships with the wake.

The factor k depends especially upon the effects of locally not streamlined parts of the ship (run, sternpost, rudderpost and appendages, rudder). These effects can be very large, as for the first time was found by *Schlupp* [21] during investigations on the effect of contra-rudders on propulsion. *Schlupp* has shown that the sometimes amazing improvement in propulsive efficiency due to these devices is caused primarily by a decrease of the thrust deduction, whereas the original idea to regain the tangential losses of the slip stream has generally a secondary importance only. Therefore, the streamlined rudder is nearly equivalent to the contra-rudder.

A theoretical explanation of these rudder effects which involves the investigation of a system hull + propeller + rudder is still lacking, altho in principle something could be done on the basis of singularities.

c. Following *Schoenherr* [7, 35] the wake of a twin screw vessel depends on the block coefficient $C_B = \partial$ and the angle of bossings only. Perhaps here

* Because of their length they are not reproduced here.

again the afterbody coefficient ∂_A is more characteristic. No parameters are given for the position of the screw relative to the hull and for the wave formation.

Somewhat different expressions are proposed for inward turning screws and for arrangements with struts. The difference in the wake formulae due to the sense of rotation indicates that the assumption of a simple sink (or sink distribution) does not picture adequately the action of the propeller flow on the hull.

d. The thrust deduction formula for twin screw ships

$$t = .25w + .114 \qquad (33)$$

suggests that the concentrated effect of the bossings expressed by the constant term is more important than the average wake value.

7. The *influence of changes in the forebody on thrust deduction* has been studied by various authors [26] [27]. The comparatively small alterations of the forebody in question can produce effects on the wave pattern only, leaving the other flow "components" (potential and frictional wake) at the stern nearly the same. Following theory, the wave formation has only a small bearing on the thrust deduction coefficient t, so that $t_w \cong 0$. Hence, we should expect that the thrust deduction is practically invariant to changes in the forebody while changes in the wake fraction are imaginable depending upon the different wave patterns. This agrees on the whole with a remark made by Emerson [25]. However, a thorough investigation on 3 models with different forebodies, due to Troost, discloses an appreciable influence of the entrance on the thrust deduction [27]. Because of the large size of the models and adequate turbulence stimulation, we must presume that the results are not spoiled by unstable flow and represent a fact which endeavors to extend the theory.

8. A considerable amount of mathematical analysis has been performed in a paper on thrust deduction by *Bassin* [24], which pretends to extend Dickmann's results.

Unfortunately, the investigation includes basic errors: in applying Lagally's theorem Bassin obtains a term representing a self-induction of the propeller sink system which is obviously wrong, as the velocity due to the sink itself must be excluded when calculating the force

$$F = -\rho, vQ \qquad (12)$$

By a double error he succeeds in proving Helmbold's formula (31). Thus the results must be applied with great caution notwithstanding the elegance of the method used.

Finally, we mention a paper by Lefol [34]. Although this work is partly based on modern literature, the present writer does not see any real advance compared with more elaborate earlier publications, except some small corrections. Thus it must be concluded as has been pointed out before that Dickmann's papers [1, 2, 3] still represent the most advanced publications on the subject.

9. *Correlated problems.* The changes of pressure on a hull due to a working propeller have important bearing on other problems in naval architecture. Well known is F. Lewis' research on hull vibrations [28] caused by the nonuniform motion of water in the region of the propeller.

Less known seems to be the influence of the propeller field on the steering qualities of twin and multiple screw ships. By changing, stopping, or reversing the revolutions of one propeller we change the corresponding pressure field around the stern of the ship. Thus, a transverse force K on the stern is produced which may be considerably higher than the thrust deduction force tT Figure 10. The turning moment KL_k has the same sense as the moment due to the *propeller* thrust, but because of its large lever, L_k, with respect to the center of gravity of the ship its magnitude may exceed by far the latter [22].

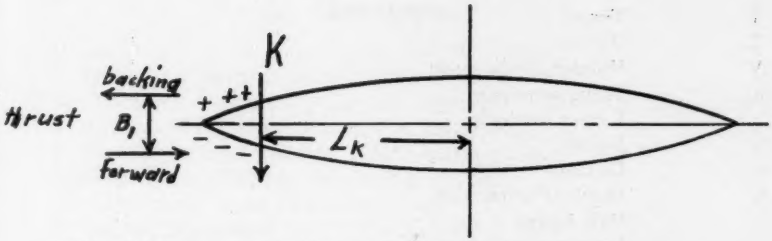

FIG. 10—Influence of Backing of a Propeller on the Steering Process

SUMMARY

The application of the source and sink concept to the system ship and propeller leads to a satisfactory explanation of the various phenomena summarized under the notation "thrust deduction." The quantitative analytic evaluation of the forces involved, altho in principle successful, meets still some difficulties and there are some important gaps between results of theory and facts. Thus, there remains a wide field for systematic experimental investigations which can be planned and guided by the present theory. One basic problem—the influence of the scale effect on the thrust deduction, especially the relation between the corresponding values for the model and the ship—cannot yet be rigorously solved; theoretical considerations indicate, however, that the common assumption following which the thrust deduction coefficient t is roughly the same for the model and the ship may be a reasonable approximation especially when the size of the model is large.

LIST OF SYMBOLS

A	Area, especially propeller disc area
A(x)	Sectional area curve
A_M	Area of maximum section
A_∞	Section of propeller race far behind
$C_B = \partial$	Block coefficient
$C_V = \chi$	Vertical prismatic coefficient
$C_{VA} = \chi_A$	Vertical prismatic coefficient of the afterbody
$C_{VF} = \chi_F$	Vertical prismatic coefficient of the forebody
D	Diameter
F	Force
$\bar{J}$	Rate of advance
K	Force
L	Ship length
L_K	Lever
L_l	Lift
M	Total moment of doublet distribution
N	Number of revolutions
Q	Total output of a source distribution
R	Resistance

T	Thrust
T_w	Period
V	Volume displacement
a	Wave amplitude
a	Larger semiaxis
b	Radius
e	Distance
h	Depth of immersion
l	Half length
$m(x)$	Doublet distribution
m_o	Maximum ordinate of distribution
n	Normal
p	Pressure; Δ_p is pressure difference
q	Source distribution
r	Distance
$s' = u/v_o$	Slip stream ratio
t	Thrust deduction
t_p, t_f, t_w	Potential (displacement), frictional, wave thrust deduction
t_o	Thrust deduction in the moored condition
u	Slip stream velocity
v	Velocity
v_o	Constant speed of advance
w	Taylor's wake fraction
w_p, w_f, w_w	Potential (displacement), frictional, wave thrust deduction
x, y, z	Coordinates
Γ	Circulation
$\Sigma = \frac{Q}{4\pi}$	Strength of source
η_o	Propulsion efficiency
η_{pr}	Propeller efficiency
μ	Doublet strength distribution
ρ	Density
σ	Source strength distribution
τ	Load factor
τ_r	Resistance load factor

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RADIOMETRY AND ALL-WEATHER NAVIGATION

J. S. KELLY AND R. G. STILES

THE AUTHORS

MR. JOHN S. KELLY was born in Louisville, Kentucky in 1922. He attended Western Kentucky Teachers College in 1940-42. In 1942 his education was interrupted by the War and the years 1942-45 were spent studying, teaching, and servicing radar systems for the Signal Corps. In 1945 he re-entered Western Kentucky Teachers College and received a B.S. degree in physics in 1946. He was employed as a Research Associate in a rocket development project at the Allegany Ballistics Laboratory of Hercules Powder Company. In 1947 and 1948 he attended Ohio State University, taking graduate courses in physics and mathematics. In 1948 he joined the Infrared Equipment Section of the Electronics Design Division of the Bureau of Ships.

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Man has depended on the sun and stars for guidance across the seas and oceans since the birth of navigation. Determination of his exact position, however, has been limited to periods of relatively clear weather. The purpose of this paper is to show how radiometric techniques may be used to overcome in part the visibility limitations of celestial navigation.

It has been known for many years that bodies above absolute zero in temperature emit thermal radiation throughout the frequency spectrum. The spectral characteristics and quantity of energy emitted are functions of the absolute temperature. It is only recently that it has become known that the sun radiates an appreciable amount of energy in the radio frequency and microwave regions. The rapid advance of microwave techniques in the last decade has made possible the development of a *radiometric sextant*. The term "radiometric" is de-

rived from radiometry, the science of measurement of radiant energy.

The sun's microwave emission can be picked up by a highly directional antenna and detected by very sensitive receiving equipment. During periods of excessive sunspot activity this radiation or noise is much greater in the longer wavelength regions. The shorter wavelength region between about 0.3 and 2.0 cm seems to have a relatively constant level regardless of sunspot activity. This is one reason that the shorter wavelength region has been chosen as the band in which to operate the radiometric sextant.

Planck's black body radiation law is used as a basis for developing an expression for the energy that a microwave antenna will intercept when directed at a given hot body.

Planck's radiation law states that for a black body

$$\psi = \frac{8\,\pi\,ch}{\lambda^5} \times \frac{1}{\varepsilon^{\frac{ch}{\lambda KT}} - 1}$$

where

ψ_λ = density of radiation for a given wavelength λ

λ = wavelength in cm.

h = Planck's constant.

K = Boltzman's constant.

c = Velocity of light.

T = Absolute temperature of the radiating body.

This expression can be expanded in series form and simplified for the sun by ignoring the higher order terms. The result is the Rayleigh-Jeans formula

$$\psi_\lambda = \frac{8\,\pi\,KT}{\lambda^4}$$

This formula indicates that the radiation density emitted by the sun is directly proportional to its absolute temperature and inversely proportional to the fourth power of its wavelength.

While this expression indicates the energy that is emitted, the amount received by an antenna at any distance will be significantly smaller. This reduction in density is due primarily to three factors, (1) the inverse square law, (2) atmospheric absorption and (3) in some cases, atmospheric refraction.

The inverse square law states that the energy density at any point is inversely proportional to the square of its distance from the source. This reduction in energy is relatively constant for any given distance and applies equally to all wavelengths.

On the other hand, atmospheric absorption is not constant and varies widely with both wavelength of the radiation and with weather conditions. For most wavelengths emitted by the sun under adverse weather conditions the atmosphere is virtually opaque. Fortunately at some wavelengths a detectable portion of the sun's energy penetrates the atmosphere even under the most severe weather conditions. Among these wavelengths at which energy penetrates is the band from about 0.3 to 2.0 centimeters mentioned above.

Refraction plays a minor part in the energy reduction in this band. When the sun is within 5 degrees of the horizon a radiometric sextant is likely to give false elevation indications as a result of refraction.

The sun cannot be considered as a point source of energy since it subtends a solid angle comparable in size to the major lobe of a highly directional antenna. Special antenna techniques must be used in the radiometry field. Here it is customary to express the energy radiated by a body in terms of its absolute temperature rather than in watts as in a radio transmitter. It is therefore convenient to consider the power received in terms of an effective antenna temperature. This effective tem-

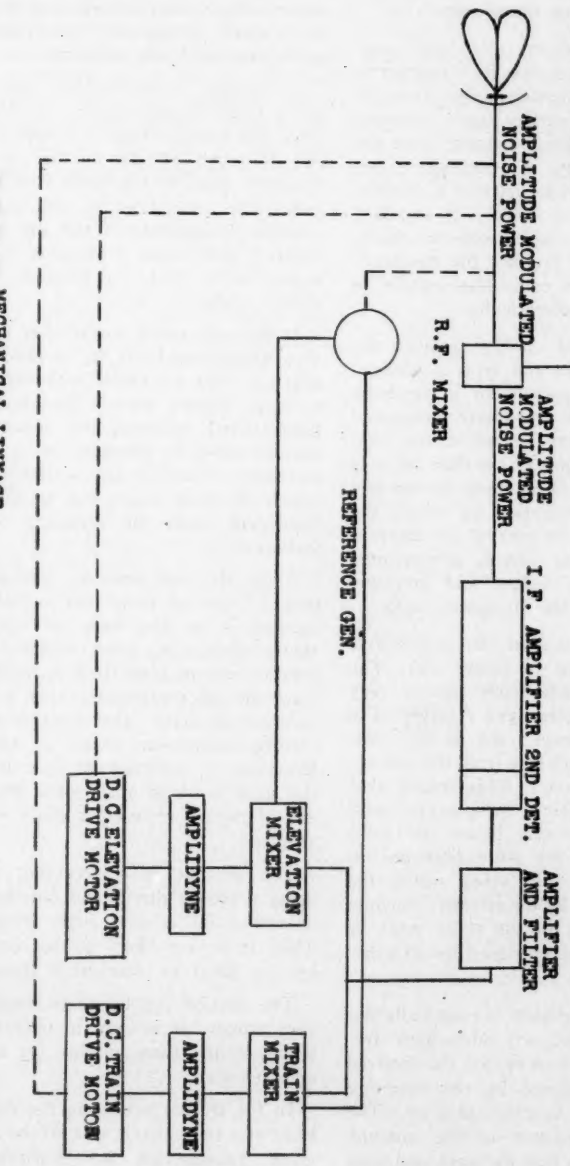
AUTOMATIC RADIO SEXTANT
SCANNING ANTENNA
AMPLITUDE MODULATED NOISE POWER
LOCAL OSCILLATOR
AMPLITUDE MODULATED NOISE POWER
R.F. MIXER
I.F. AMPLIFIER 2ND DET.
AMPLIFIER AND FILTER
REFERENCE GEN.
ELEVATION MIXER
TRAIN MIXER
AMPLIDYNE
AMPLIDYNE
D.C. ELEVATION DRIVE MOTOR
D.C. TRAIN DRIVE MOTOR
MECHANICAL LINKAGE

FIGURE 1.

perature bears a definite relationship to the temperature of the source.

Instead of receiving modulated energy from a radio station the radiometric sextant receives noise energy from the sun. This noise energy has a constant value for any radial distance from the center of the sun. A scanning system can be introduced to produce a modulation of this noise energy. A standard reference signal coupled with this modulated signal will produce the necessary error voltages to cause the sextant to track the sun automatically.

The amount of energy received depends on the size and type of antenna used. For this instrument a parabolic dish is used with a properly terminated wave guide pickup located at the focal point. The diameter of the dish depends on the accuracy of tracking desired and the frequency radiation to which the system is tuned. In general the aperture of the reflector is directly proportional to the accuracy desired and inversely proportional to the frequency used.

A block diagram of the radiometric sextant is shown in figure (1). The antenna waveguide feeds into a very sensitive superheterodyne receiver. The receiver noise level must be very low since its noise and that from the sun are similar in character. This means that the effective receiver noise temperature must be considerably below the noise temperature of any point observed on the sun surface. In other words the signal produced by the effective antenna temperature due to sun noise must be greater than that produced by all other sources of noise.

The receiver design is essentially the same as that of any ultra-high frequency receiver except that the received energy is modulated by the scanning action of the antenna pick-up. The primary requirements of the antenna and receiver are that the gain and scan angle be so chosen that an error voltage is generated. The magnitude of this error voltage must be sufficient to actuate a servo system and thereby accomplish automatic sun tracking.

Particular consideration must be given to the design of the servo system since the angular rate of travel of the sun is much greater in the vertical direction than in the horizontal direction. This variation in the angular velocity components of the sun is not constant but varies with time of day, season of the year, and location on the earth's surface.

If the radiometric sun tracker is used as a navigational aid, its elevation and bearing must be given with reference to some known plane. Therefore, for navigational purposes the radiometric sextant must be mounted on a stable platform. Obviously the accuracy with which elevation angles can be given is dependent upon the accuracy of the stabilization.

Since the sun position information that is derived from the radiometric sextant is in the form of electrical energy almost any kind of signal presentation can be used. If it is desired to track the sun continuously then a paper recorder or some other continuous recording mechanism would be suitable. However, if intermittent operation of the instrument is anticipated then the use of meters or vernier dials will be adequate.

The sextant is a receiving device using a highly directional antenna and operating on a very high frequency. Thus it is not likely to be disturbed by any local or man-made static.

The sextant can be made simple and very sturdy. It is easy to operate and maintain and thus suitable for use on ships at sea.

In the studies preceding the development of a radiometric sextant the generation, propagation and reception of microwave emission due to temperature

were analyzed. Particular attention was given to propagation of this energy through the atmosphere. Further investigations included determination of the usefulness of microwave thermal radiation from other celestial bodies such as the moon and stars. The results indicated that the sun is the only source radiating enough energy to assure reliable tracking with the sextant. The moon, however emits or reflects enough energy for tracking under optimum atmospheric conditions.

In conclusion it can be said that the radiometric sextant affords a method for obtaining the position of the sun in all-weather conditions with an accuracy comparable to that of an optical sextant.

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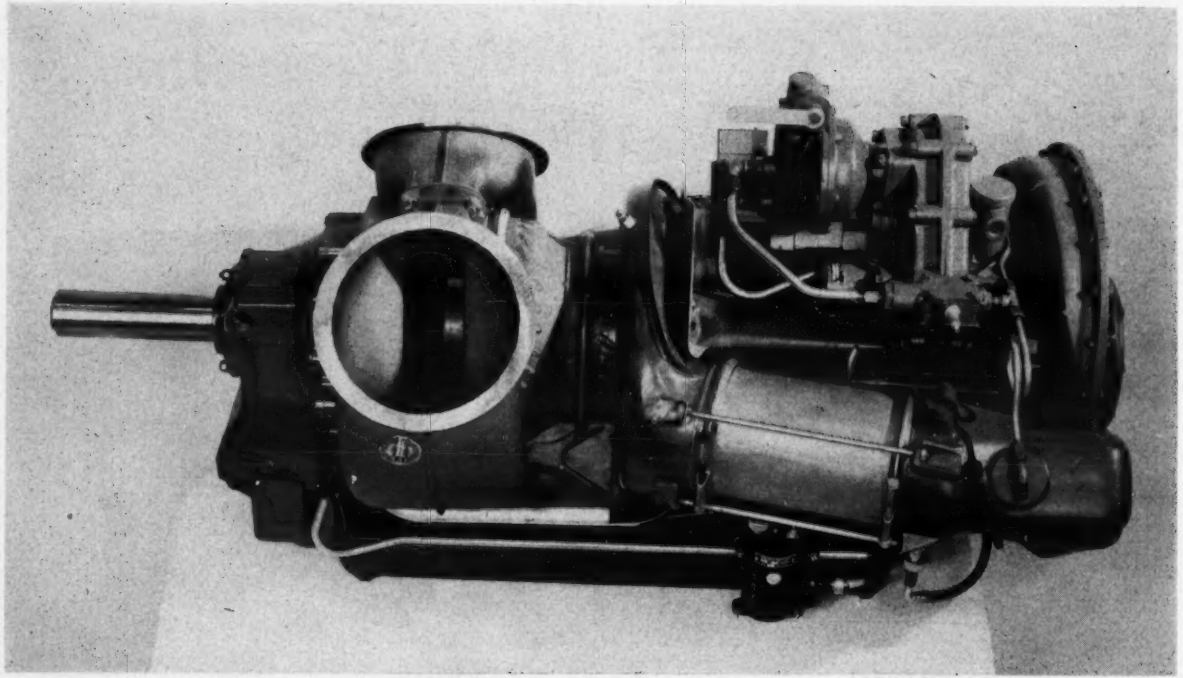
PART TWO

REPRINTED ARTICLES

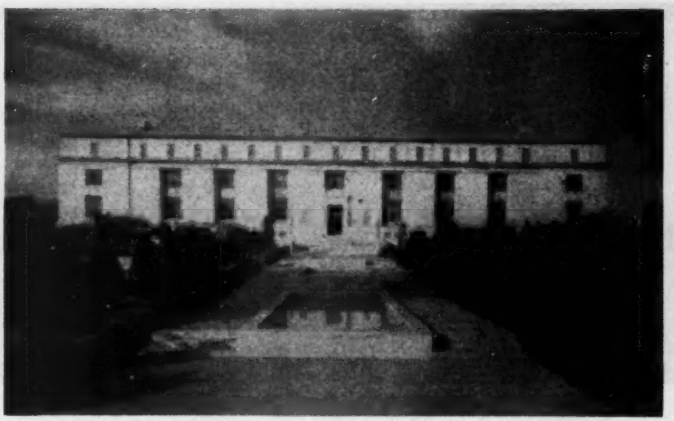
The articles contained in this Part Two represent those which, in the opinion of the editorial staff, are the most valuable which have been gleaned from recent issues of contemporary publications.

This material was formerly published under the heading "NOTES". It has been given somewhat more prominence and made more readable to enhance its value. The editors' purpose here is to provide a convenient repository to readers of the JOURNAL, for articles originally published elsewhere which contribute to the purpose of the Society: to further the advancement of naval engineering.



Official United States Naval Photograph

Gas Turbine for Small Boat Propulsion —
Horsepower 175, weight 220 pounds, length 40 inches, width 24 inches, height 23 inches.



The Academy Building

THE NATIONAL ACADEMY OF SCIENCES AND THE NATIONAL RESEARCH COUNCIL

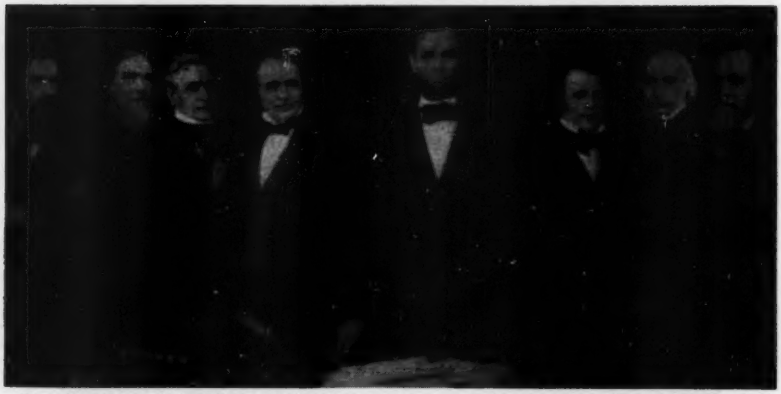
RAYMOND L. ZWEMER, EXECUTIVE SECRETARY

ACKNOWLEDGMENT

Reprinted from "Science," September 3, 1948, Vol. 108, No. 2801, pages 234-238.

The National Academy of Sciences has been from its origin closely associated with the American Association for the Advancement of Science, and both of them with the Smithsonian Institution, which was founded somewhat earlier "for the increase and diffusion of knowledge among men."

Just a hundred years ago the American Society of Geologists and Naturalists broadened its scope to become the American Association for the Advancement of Science, several members of which in turn were instrumental in helping to establish the National Academy of Sciences.



The founders of the National Academy of Sciences as painted by Albert Herter. Left to right W. B. Patterson, A. D. Bache, Joseph Henry, Louis Agassiz, Abraham Lincoln, Senator Henry Wilson, Admiral Charles H. Davis, and B. A. Gould.

In connection with the Centennial Celebration of the AAAS it is interesting to note that 11 of the 15 presidents of the National Academy were also presidents of the AAAS, and, of the 97 presidents of the AAAS, 84 are on the roles of the Academy.

It was at a meeting of the AAAS in 1851 that Alexander Dallas Bache, grandson of Benjamin Franklin, pointed out in his retiring presidential address that "an institution of science supplementary to existing ones is much needed in our country to guide public action in reference to scientific matters." A further quotation from this address is as pertinent today as it was then:

> Our country is making such rapid progress in material improvements that it is impossible for either the legislative or executive departments of our Government to avoid incidentally, if not directly, being involved in the decision of such questions. Without specification, it is easy to see that there are few applications of science which do not bear on the interests of commerce and navigation, naval or military concerns, the customs, the light-houses, the public lands, post-offices and post-roads, either directly or remotely. If all examination is refused, the good is confounded with the bad, and the Government may lose a most important advantage. If a decision is left to influence, or to imperfect knowledge, the worst consequences follow.
>
> Such a body would supply a place not occupied by existing institutions, and which our own is, from its temporary and voluntary character, not able to supply.

Twelve years later, in February, 1863, Joseph Henry, secretary of the Smithsonian Institution, Alexander Dallas Bache, superintendent of the Coast Survey, and Charles H. Davis, chief of the Bureau of Navigation, Navy Department, were named as a commission to report on various matters of science and art, but chiefly of a practical import and relating to the physical sciences. Davis' letter of appointment is preserved in the archives of the Navy Department. The members of this commission were active, in consultation with others, in forming a plan for a

National Academy of Sciences which would have the dual nature of honoring members elected to the group and of serving as adviser to the Government. The plan culminated in an Act of Congress which was passed by the Senate and by the House of Representatives and signed by President Abraham Lincoln—all on Tuesday, March 3, 1863.

In carrying out subsequent requests of Federal government agencies for advice from the Academy, it was found that many problems required the combined action and thoughts of a specific group of people. Committees were therefore named, and a brief mention of some of these may be interesting as illustrations of the questions presented.

Advice was requested on weights, measures, and coinage. A committee on this subject is still in existence and has been called on from time to time. Other committees dealt with metric standards for the states; with philosophical and scientific apparatus; with protection of the bottoms of iron vessels; with magnetic deviation in iron ships; with the astronomical day, the solar eclipse of 1886, and the erection of a new naval observatory; and with questions on meteorological science and its application. The Department of State requested an Academy committee to look into the matter of restoration of the faded writing of the original manuscript of the Declaration of Independence. As a result of the report of this committee the manuscript was removed from exhibition in 1893, sealed between glass plates, and placed in a steel safe, where it was no longer exposed to light and was secure from careless handling.

The Department of Agriculture requested committees on silk culture and on sorghum sugar, which was suggested as a substitute for the then-scarce cane sugar.

The Department of the Interior in 1896 requested information on a rational forest policy for the forested lands of the United States. An official expression from the National Academy was requested upon the following points:

(1) Is it desirable and practicable to preserve from fire and to maintain permanently as forested lands, those portions of the public domain now bearing wood growth for the supply of timber?

(2) How far does the influence of forest upon climate, soil, and water conditions make desirable a policy of forest conservation in regions where the public domain is principally situated?

(3) What specific legislation should be enacted to remedy the evils now confessedly existing?

The members of the committee appointed spent three months in laborious study and inspection of forests and found widespread devastation caused by fires started by careless or ignorant campers or hunters, devastation by herds of animals, and theft of timber. The preliminary report to the Secretary of the Interior recommended the establishment of 13 new forest reservations covering more than 21,000,000 acres. The report was forwarded to President Cleveland on February 6, 1897, and on February 22 the President proclaimed the establishment of these reservations. The full committee report on the inauguration of the forest policy was comprehensive in scope and contained definite recommendations for the establishment of a National Forestry Service.

Soon after the organization of the National Academy of Sciences, Alexander Dallas Bache added a codicil to his will leaving a trust fund, the income of which should be for the "prosecution of researches in physical and natural science by assisting experimentalists and observers in such manner and in such sums as shall be agreed upon by the board of direction in the said clause named." The first grant for scientific

Meeting of the National Academy of Sciences in Mineral Hall, Smithsonian Institution, about 1871: 1, Joseph Henry; 2, Mary Henry; 3, W. J. Rhees; 4, F. W. Clarke; 5, J. S. Newberry; 6, J. C. Dalton; 7, J. E. Hilgard; 8, J. J. Woodward; 9, Peter Parker; 10, Albert M. Mayer; 11, William Ferrel; 12, Benjamin Silliman; 13, C. E. Dutton; 14, Emil Bessels; 15, Arnold Guyot; 16, J. H. C. Coffin; 17, B. A. Gould; 18, Elias Loomis; 19, C. A. Schott; 20, George Eugelmann; 21, Benjamin Pierce; 22, Simon Newcomb; 23, Lewis H. Morgan; 24, A. A. Michelson; 25, John S. Billings; 26, Weir Mitchell; 27, Frederic M. Endlich.

research was made in 1871 to Prof. J. E. Hilgard in connection with the magnetic survey of the United States. The chairman of the trust fund committee was Joseph Henry. Through this fund and subsequent bequests, the Academy has been given an important instrumentality for the promotion of scientific research. There are now 8 Trust Funds of the Academy which give grants; additional ones have been established for the awarding of medals and honoraria for distinguished research.

Notable contributors to the advancement of science in this and other countries are honored by the awarding of medals and prizes.

Stress of war brings problems soluble only by scientific research, and successful research requires trained investigators. In April 1916, when the entry of the United States into World War I was being foreseen, the National Academy of Sciences offered its services to the President of the United States. The result of this offer is appropriately given in the words of George Ellery Hale, who did so much in the establishment of the National Research Council:

> President Wilson at once requested that steps be taken to organize the research agencies of the country, not solely with respect to the necessities of possible war, but also because of the importance of developing and utilizing them more effectively under peace conditions. This led to the establishment in September 1916 of the

National Research Council, a federation of governmental, educational, privately endowed, and industrial research agencies, resting upon the charter of the National Academy, and extending the scope of its activities into every branch of the mathematical, physical, and biological sciences, and their applications to engineering, medicine, agriculture, and other useful arts.

Thus our National Research Council differs fundamentally in several respects from the Advisory Councils for Scientific and Industrial Research recently established by the British, Australian, and Canadian Governments, though its general objects are similar to theirs. Those Councils are branches of the Government, with officers appointed by the party in power and thus subject to political influences and exigencies. The National Research Council is closely connected with the Government, through the charter of the Academy and the Executive Order issued by President Wilson on May 11, 1918, which provides for the cooperation of Government Departments, and for the appointment by the President of representatives of their scientific and technical bureaus to membership in the Research Council on the nomination of the National Academy of Sciences. The constitution of the Research Council is determined, however, by the National Academy, and this assures its scientific soundness. Moreover, the scheme of organization adopted by the Academy provides that the several divisions of the Research Council shall be made up of nominees of leading national scientific and technical societies interested in research. This gives the Council a thoroughly representative character, and makes it an actual federation of research agencies. Thus it is peculiarly well fitted to secure the cordial cooperation of the numerous elements that must work in harmony, if extensive plans for cooperation in research are to be carried into effect.[1]

For two years the Research Council acted as an emergency or a temporary organization to assist the Government in coordinating the scientific resources of the country. On May 11, 1918, by Executive Order, the President requested the Academy, in view of the new and important possibilities of science and research in time of peace as well as war, to establish the Council on a permanent basis. The purposes of the Council can best be expressed by the Executive Order itself.

EXECUTIVE ORDER

The National Research Council was organized in 1916 at the request of the President by the National Academy of Sciences, under its congressional charter, as a measure of national preparedness. The work accomplished by the Council in organizing research and in securing cooperation of military and civilian agencies in the solution of military problems demonstrates its capacity for larger service. The National Academy of Sciences, is therefore requested to perpetuate the National Research Council, the duties of which shall be as follows:

1. In general, to stimulate research in the mathematical, physical and biological sciences, and in the appli-

[1] From *The national importance of scientific and industrial research*, by George Ellery Hale and others.

cation of these sciences to engineering, agriculture, medicine and other useful arts, with the object of increasing knowledge, of strengthening the national defense, and of contributing in other ways to the public welfare.

2. To survey the larger possibilities of science, to formulate comprehensive projects of research, and to develop effective means of utilizing the scientific and technical resources of the country for dealing with these projects.

3. To promote cooperation in research, at home and abroad, in order to secure concentration of effort, minimize duplication, and stimulate progress; but in all cooperative undertakings to give encouragement to individual initiative, as fundamentally important to the advancement of science.

4. To serve as a means of bringing American and foreign investigators into active cooperation with the scientific and technical services of the War and Navy Departments and with those of the civil branches of the Government.

5. To direct the attention of scientific and technical investigators to the present importance of military and industrial problems in connection with the war, and to aid in the solution of these problems by organizing specific researches.

6. To gather and collate scientific and technical information, at home and abroad, in cooperation with governmental and other agencies, and to render such information available to duly accredited persons.

Effective prosecution of the Council's work requires the cordial collaboration of the scientific and technical branches of the Government, both military and civil. To this end representatives of the Government, upon the nomination of the National Academy of Sciences, will be designated by the President as members of the Council, as heretofore, and the heads of the departments immediately concerned will continue to cooperate in every way that may be required.

(Signed) WOODROW WILSON

The White House
11 May 1918

An appreciable part of the war work conducted by the Council or under its auspices did not terminate in 1918 but was continued for longer or shorter intervals, and some of the committees are still operative, having been assimilated into the peacetime organization. This was peculiarly true of those whose work was most closely related to industrial problems, many of which are quite as significant for times of peace as for war. Certain metallurgical researches which were continued under the Division of Engineering are cases in point.

The membership of the Research Council, numbering about 220, is now composed largely of appointed representatives of more than 90 of the major scientific and technical societies of the country, together with representatives of certain other research organizations, representatives of government scientific bureaus, and a limited number of members-at-large. These members receive their appointments from the President of the National Academy of Sciences. Representatives of the government executive agencies are appointed with the approval of the President of the United States.

Many projects which contributed directly to the successful conclusion of World War II were financed through contracts made with the Office of Scientific Research and Development, the War Production Board and other government departments and agencies. Important projects undertaken included military medicine involving extensive cooperation with the Committee on Med-

ical Research, food and nutrition, research on critical metals and other materials, and certain problems of actual warfare, many of them highly confidential.

The National Research Council administers a large number of fellowships generously supported by organizations such as the Rockefeller Foundation, the American Cancer Society, Merck & Company, Inc., the Radio Corporation of America, the National Foundation for Infantile Paralysis, and, most recently, by a large grant from the Atomic Energy Commission.

Neither the Academy nor the Research Council receives appropriations directly from the Government. Support for the central organization and maintenance of the building and grounds is derived from an endowment which was a gift of the Carnegie Corporation. Special projects are financed by contracts with government agencies, nonprofit philanthropic organizations, and foundations. Grants-in-aid of research are available from a number of Trust Funds and from some of the resources enumerated above.

The National Science Fund was established by the National Academy of Sciences in April 1941. The Academy receives, and the National Science Fund applies, large or small gifts for all physical and biological sciences. The Fund also offers its services as adviser to any prospective donor to science.

Giving money wisely is not a simple task. This is particularly true of support for fundamental scientific research. Recognition of this fact led to the establishment of the National Science Fund, which offers an organization controlled by a Board of Directors composed of distinguished scientists and qualified laymen to help donors to give wisely and usefully for the advancement of science.

The *Proceedings* is the official organ of the National Academy of Sciences and of the National Research Council for the publication of brief accounts of important current research of members of the Academy and of the Council, and of other American investigators. Larger contributions to knowledge have been issued as *Scientific Memoirs*, among which might be mentioned "Report of the Eclipse Expedition to Caroline Island," "On the Temperature of the Surface of the Moon," "The Cave Fauna of North America," "The Solar and Lunar Spectrum," "Contributions to Meteorology," "Catalogue of the Meteorites of North America to January 1, 1909," "Studies Upon the Life Cycles of the Bacteria," "Panama Canal Slides," and many others.

The Academy has also sponsored, together with the Research Council, publication of a number of books, some of which have attained the rank of best sellers.

The *Biographical Memoirs* furnish much of human interest to the historical records of the Academy.

The National Research Council issues a series of Bulletins giving general sources of scientific knowledge; directories of research laboratories and personel and of scientific societies and their officers; reports upon the status of various fields of research; and special contributions of an original character. Its Reprint and Circular Series is for less extensive papers and for reprints of timely articles, some of which have had initial circulation elsewhere.

The activities of each year, reported by the president of the Academy, the chairman of the Research Council, and the chairmen of Divisions of the Research Council, are contained in an Annual Report submitted to Congress through the president of the Senate.

The building of the National Academy of Sciences and National Research Council, which was designed by the late

Bertram Grosvenor Goodhue, was completed in 1924. The land on which it stands was purchased with funds subscribed by about 20 friends of science, and funds for its erection were provided by the Carnegie Corporation.

The building is of white Dover marble, trimmed in bronze. Over the doorway is a representation of the elements with which science deals—earth and cloud, and the various forms of vegetable and animal life to man; at the apex is the sun, source of warmth and light. Bronze panels on either side of the doorway and pierced stone window grilles have woven into the scroll pattern the initials NAS and NRC, indicating the joint occupancy. The cornice of the building is composed of alternating figures of the owl and the lynx, typifying wisdom and alert observation, with a coiled serpent at each corner. The bronze window panels depict the progress of science from Greek to modern times by means of a succession of the great founders. The bronze doors portray 8 episodes in the history of science from Aristotle to Pasteur.

No scientific laboratories are maintained by the Academy or Research Council. Instead, they seek to coordinate the work of individual scientists and laboratories dealing with large problems in the fields of science. Among the means of carrying out these aims are conferences, technical committees, surveys, sponsorship of new organizations for research and of scientific publications, and the administration of funds for research projects.

This brief description of the very complex structure and function of the National Academy of Sciences and the National Research Council will, it is hoped, serve to remind the reader of the part these organizations have played in the development of science in this country during much of the past 100 years.

AERONAUTICS

ACKNOWLEDGMENT

The 125th Anniversary Issue of the "Journal of the Franklin Institute," January 1951, contains a symposium titled "Science and Tomorrow." This symposium consists of fifteen papers describing possible and probable future developments in various branches of science and technology. One of these papers, "Aeronautics," was written by J. C. HUNSAKER of the Massachusetts Institute of Technology.

Human flight occurred for the first time in the history of our race near the beginning of this century, December 17, 1903. The dream of flight is old. Men had long wondered at "the way of an eagle in the air." Leonardo sketched artificial wings. The Montgolfier brothers sailed with the wind in a balloon. Hardy adventurers leaped from high places with parachutes. Lilienthal slid from hill to valley in a glider two thousand times before his fatal crash. The simultaneous advent of benzine and the internal combustion engine, in the closing years of the 19th century, suggested to Langley and other pioneers the application of power to a glider to make a true flying machine. However, the principle of control in three-dimensional space was lacking. This lack was supplied in the Wright brothers' great invention.

Never has a new vehicle been born into a more favorable climate for its technical development. Applied science and the industrial revolution of the 19th century had piled invention upon invention: machine tools, railways, steamships, the electric telegraph, photography, the typewriter and typesetter, and finally the motor vehicle. It seemed, at the dawn of our century, that man needed only to accomplish the conquest of the air to dominate his planet. In our own time man has achieved this conquest to an extent unforeseen by the most optimistic.

The Wright airplane disclosed a sustaining wing structure, engine-driven propeller, and means for controlling attitude in pitch, roll and yaw. This basic type has continued to the present day. Its performance was rapidly improved by application of the advancing technology of the new century. Research and development were stimulated by generous national subventions, and two wars poured billions into the production of bigger and better flying machines.

In his 1950 Wilbur Wright Memorial Lecture.[1] Sir Richard Fairey traced

[1] *Jour. R. Ae. Soc.*, Vol. 54, pp. 405-432, London, 1950.

fifty years of expenditure on aeronautics, world-wide, making intricate allowances for the shrinking values of money and varying exchange rates. The curves of Fig. 1 show that expenditures of America and Britain were relatively modest during the period between wars, but that the world total rose abruptly between 1934 and 1939 into the billions (Germany, Japan, Italy, Russia). Sir Richard stops his analysis with 1948, by which time the total expenditure by all nations in peace and war adds up to 256 billion U. S. dollars since the Wright brothers made their contribution to the technology of transportation. Orville Wright was not unaware of the military value of the airplane, since the first sale was to the U. S. War Department. However, he always contended that he and his brother Wilbur thought of their airplane as a contribution to international communications, trade and good will. Perhaps the next fifty years will prove him to have been right in the long run.

Designers were at first the inventors, then engineers and scientists. The demands of the airplane led to the creation of strong light alloys, high octane gasoline, high output engines, and special operating equipment using radio, radar and auto pilots. A new science of aerodynamics was evolved to serve designers. New impulses were given to the classical but somewhat sterile theories of hydrodynamics, elasticity, radiation, gyroscopics, and navigation. Old ideas for a gas turbine were resurrected and applied with spectacular success.

Taking speed records of propeller-driven airplanes as a measure of progress, the increase in 47 years has been from about 40 to nearly 500 miles per hour, or at the rate of some 10 miles per year of effort. Simply projecting this trend suggests that the next 50 years should bring the airplane's speed record to 1000 miles per hour. A fallacy must

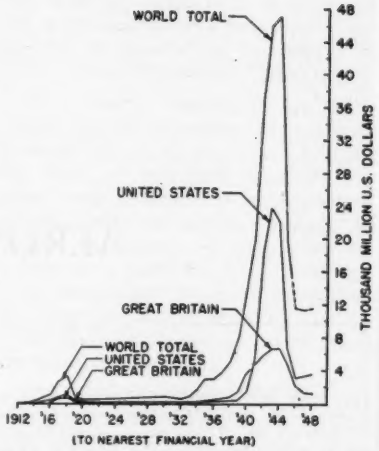


FIG. 1.—World expenditure on aviation

be present here, because the newspapers inform us that jet-propelled research airplanes have repeatedly flown at supersonic speeds. This sounds like 1000 miles per hour already.

Closer examination of the position shows that the jet-propelled airplane is not the airplane of the Wright brothers; something new and revolutionary has been added. A radically lighter and more powerful means of propulsion eliminating the propeller is a mutation that upsets statistics of past growth. The engine and propeller-driven airplane has indeed made a normal growth curve, topping off between 1940 and 1950, with a maximum sea level speed of the order of 450 miles per hour.

The performance of jet-propelled airplanes is too recent to establish a trend from which to venture a forecast. All we know is that we shall have to do with a new kind of airplane to which vastly increased thrust can be applied. How fast will it go? The answer seems to be as fast as required.

The limits on useful speed will be imposed by practical considerations of

range, load, control, and safety. Extreme speed can only be attained with an outrageous rate of fuel consumption even when advantage is taken of the diminished resistance of the air at high altitudes. Higher speed means shorter range or the sacrifice of pay load. Furthermore, wings may be clipped to a degree that makes control for take-off and landing impractical. Pushing possibilities to the limit, one can replace the pilot by automatic or robot controls, launch by catapult or from another airplane, and expend at the end of flight. Such an ephemeral insect-like thing is the guided missile, featured by the popular press but otherwise clothed in security wrappings. Rocket-propelled for less than a minute, 12-ton German missiles landed in London from a launching point in France with a ton of explosive. The velocity exceeded 3000 miles per hour over part of the trajectory.

Exploitation of the rocket art for military purposes will no doubt continue, with substantial improvements in frightfulness over the German models. Engineers who should know better have aroused public anxiety by predicting intercontinental push-button warfare, satellite vehicles circling the earth like moons, and space ships for interplanetary excursions!

The possibility of such space ships is usually based on Dr. R. H. Goddard's concept of a multi-stage rocket. A giant rocket as big as a cruiser starts from the earth and then ejects a smaller one and so on until the last rocket escapes into space. Calculations can be made to show that this might be done at enormous expense.

Another speculative calculation can be made to show that a few pounds of fissionable material might suffice for an escape rocket. This idea shifts the problem from the source of power to the means to apply it. The atomic energy must be transferred to a working fluid, such as hydrogen, to be ejected at high velocity. The material to withstand the temperature involved is unknown, and the engineering data necessary for the development of an atomic rocket are not available for scrutiny.

We already use rockets for exploring the upper air, for accelerated take-off of airplanes and for other auxiliary purposes and, no doubt, further uses will appear. Since rockets and, to a somewhat less degree, ram-jet power plants, are so extremely extravagant of fuel, they seem likely to find their best applications to weapons.

I would hesitate to say now what might not be possible in 1999, but it is safe to predict that applications of the rocket principle for air warfare will be the subject of intense effort.

I leave out of this discussion design trends in military airplanes. The design of military airplanes, like that of warships, is governed very largely by the foreign policy and military plans of the nation, checked by intelligence of actual or potential foreign equipment, and controlled by the general state of technology at a given time.

The international situation for the next 50 years is unpredictable. There is now an evident trend toward preparation for war. Under this trend, aeronautical development is now directed toward the needs of national security but technical advances in military aeronautics are ultimately applicable to civil uses. We have twice observed the stimulating effect of war on postwar air transportation.

In a period of peace, research results, as they disclose new knowledge, suggest to designers in a competitive industry new solutions. From their experiments come practical improvements, usually minor, but over the years their effect is cumulative.

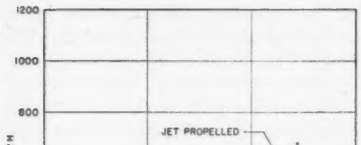


FIG. 2.—Sea level, airplane speed records (After H. Luskin, Douglas Aircraft Co.)

The trends of immediate improvement are usually evident from a comparison of current designs with research data not yet applied. There is always a time lag before research findings come into general use, but such trends justify only short-range predictions, perhaps over a ten-year rather than a fifty-year period.

For example, it is evident that the gas turbine is revolutionary in its effect of affording more power and hence higher speed to modern airplanes. The reciprocating engine is mature and efforts to improve it have reached a stage of diminishing returns. The turbine is simpler, lighter and more compact. Its big disadvantage is its youth, and consequent occasional unreliability and a tendency to extravagance. Youth will be outgrown and hence one may safely predict reliability to be promptly established. The fuel economy is now relatively poor, but three ways to improve it are known.

First, and most readily, fuel economy can come from higher compression of the combustion air. A current compression ratio of 4 to 1 can be raised to 8 or even 12 to 1 by using more powerful compressors. The design principles for such compressors are now established. Early application should bring fuel economy at high cruising speeds down to equal that of the ordinary engine.

Second, raising the temperature of the products of combustion before entrance to the turbine will both improve fuel economy and increase power output. The current limit on allowable temperature is due to the metals available. Research indicates the possibility of better heat-resisting metals, ceramics and their combination ceramels. Furthermore, experimental schemes for turbine blade cooling indicate interesting possibilities for raising gas temperatures with present blade materials. Eventual success with higher temperature should bring fuel economy down to that of the best engines.

Third, it is known that a substantial gain in economy can be had by the use of heat exchanger surfaces to transfer some waste heat from the exhaust to the compressed air for combustion. Taken with the other two improvements, it should be possible to attain a fuel economy superior to that of any previously known aircraft power plant. However, heat exchangers will not be adopted quickly. They involve increased weight and space, and a complication that threatens reliability and ease of maintenance. Perhaps, marine and stationary gas turbines will pioneer this avenue.

I believe that the propeller is the simplest and most efficient machine for converting torque to thrust. It is man's invention. It is not found in nature. If the gas turbine is such a superior power plant, it is a natural idea to gear it to a propeller to make it more effective than when its exhaust jet alone is used to give thrust.

The jet is certainly simple. It weighs nothing but is somewhat wasteful, especially at low airplane speeds. The kinetic energy of the small diameter high-velocity jet is all lost. Only its momentum gives thrust. The propeller

also creates a jet in its "slip stream" but this is a large low-velocity jet in which the ratio of momentum (thrust) to kinetic energy is high. Good propellers have an efficiency of as much as 88 percent.

Over the years the speed of commercial air transports has lagged the airplane speed records by 15 or 20 years. When the speed record was 400 miles per hour, air transports cruised at 200. Now the new transports can cruise at better than 300 miles per hour. As military experience with high-speed flight accumulates, we may expect the speed of air transports to follow with a conservative lag but probably not so great as in the past.

It had long been considered that propellers become inefficient at an airplane speed of much over 400 miles per hour. Then the tip speed of the propeller blades became excessive. However, recent research suggests a change in propeller design which should render propellers effective beyond 500 miles per hour, and perhaps to 600. There are practical difficulties to be overcome, but discounting them, it appears that the gas turbine driving a propeller promises the more powerful drive needed to get higher transport speed, while retaining the high efficiency of the propeller. The prediction of the early appearance of faster air transports with geared gas turbine-propeller drive is easy.

Whether, in a more distant future, there will be reason to fly passengers at supersonic speeds is perhaps doubtful. There certainly will be good reason for bombers to fly at the maximum speed the art permits. When they do, propellers can not be used and jets will take over. When air transport wishes to emulate the speed of bombers, they also will have to use jet propulsion.

In the present state of knowledge, considerations of economy favor the propeller-gas turbine power plant. For routes with stops at 1000 mile intervals, the advantages of speed may be controlling, and jet propulsion gas turbines used. For feeder line local service, for freight and general utility work, for private (not common carrier) airplanes the propeller and engine seem best.

Any engineer will agree, I think, that the different means of propulsion will be used in future where there is a real advantage. Research and development may change relative merits from time to time, and unpredictable inventions may occur. Just now, it appears that the gas turbine has good possibilities for substantial improvement, whether used for jet propulsion or to drive a propeller.

Air transportation is already big business. In 1949, more than 16,000,000 passengers were carried by U. S. air lines, with only one fatality per 100,000,000 passenger miles. Statistically, the safety record looks good. The risk is certainly insurable, but this does not comfort the individual passenger when he reads of a spectacular crash in his newspaper. Nor is the passenger comforted when his flight is cancelled by reason of bad weather. The cancellation is in the interest of his safety, but he thinks first of his missed appointment and general inconvenience.

Figure 3 shows the continuous rise in air transport speeds for the last 25 years, but the mean line always lies well below the record speeds of Fig. 2. The new British jet-propelled transports, COMET and JETLINER, promise the continuation of the secular speed increase we have been accustomed to. I have no reason to project the straight line to intersect 1000 miles per hour at 1970. This would be outside the chart, and over into the region of transonic speed where critical aerodynamic trouble can be predicted.

Too rapid adoption of possible design improvements in air transport and unusual efforts to maintain schedules in

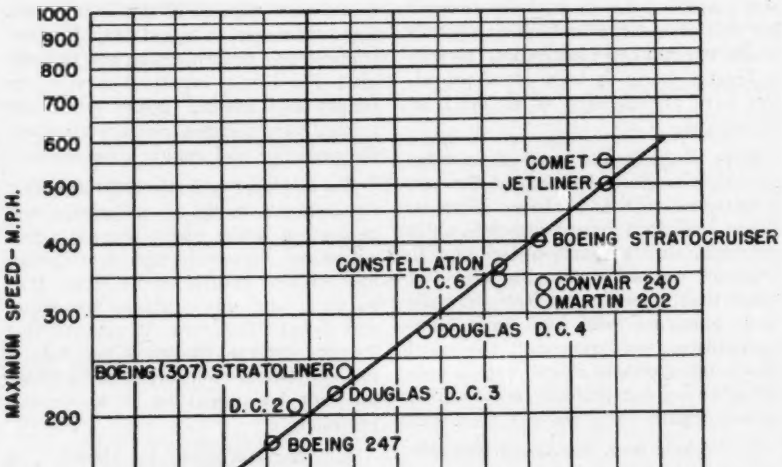


FIG. 3.—Speed of transports (From *Aviation Week*, May 22, 1950)

bad weather work against safety. Air transport cannot proceed at once to exploit many possibilities of the art suggested by current research. A number of difficult problems must first find practical solutions. No doubt solutions will be found, but the timing is uncertain. The next fifty years should bring solutions to the following difficulties that now appear formidable.

1. *Fatigue*—As airplanes fly faster, the wings must be thinner and of sharper profile. Such wings are flexible. They bend and twist in gusty air and under the shock of landing. The effect of rough air is magnified by higher speed. The structure of the wings is strained repeatedly and may gradually lose strength by fatigue. Research has accumulated data as to the repetitions of strain per 1000 hours of flight on various transcontinental and transocean routes, but is as yet unable to predict the safe life of the airplane.

2. *New Materials*—The fatigue problem is allied to the problem of new materials and methods of construction to make stiffer wings. For example, there are possibilities in the use of adhesives instead of rivets, sandwich construction of metal and plastic, new alloys and, finally, the recent availability of titanium.

3. *Stability and Control*—To fly faster requires new configurations to avoid the aerodynamic disturbances that appear at critical speed near the speed of sound. Swept-back wings have been

found valuable at high speeds but unfortunately introduce trouble with control when approaching a landing. Also some high-speed airplanes exhibit stability vagaries which seem too quick for a human pilot to cope with. This suggests more dependence on automatic controls and servo mechanisms.

4. *Physiology*—Airplane design must always consider the limitations of human physiology. The paragraph above refers to the pilot's reaction time. The human air-breathing animal requires definite rations of oxygen, carbon dioxide and water vapor, in a strictly limited range of temperature and pressure. If he be housed in an air-conditioned cabin with a pressure corresponding to an altitude of some 8000 ft., he is quite comfortable. However, in order to attain high speed, air transports of the future might fly at 40,000 ft. or higher. Mechanical failure to maintain cabin pressure could result in fatal decompression. Air transport operators presumably will require assurance that the chance of failure of cabin pressure will be as remote as structural collapse of a wing.

5. *Air Navigation*—The limitation of the present airway navigation and traffic control systems prevent the expeditious and safe handling of the current traffic load. Elements of a comprehensive system of radar range, surveillance and precision-approach ground equipment are already being installed at some airports and military flying fields. A complete system covering the North American continent could be followed by its world-wide extension during the next 50 years, if the international climate is favorable to free communications and traffic. The full development of all-weather flying depends on this.

6. *Airports* — The great potential growth of air commerce depends not only on air navigation facilities but also on the availability of suitable airports. The higher cruising speeds now anticipated require, for economical operation, higher wing loading. Take-off and landing characteristics limit such fast air transports to the largest airports. The newer airliners are probably at the limit for safe operation from the majority of large airports. It is probable that runway lengths will be increased at some of the great international airports but the larger number of municipal airports cannot expand. This will bring about a distinction between high-performance air transports for long distance routes, and air transports of more modest performance, making frequent short flights between airports located near every considerable center of population, and feeding in to the large transcontinental and international airports.

7. *Helicopters* — Air transport between airports cannot reach full commercial stature, unless improved means are developed to get the passengers, mail and freight to their ultimate destination. Motor vehicles are the present means, but are costly and slow. For short flights, time in the air may be exceeded by the time required for ground transport. The helicopter appears to have the characteristics required to solve this problem but at present is complicated, costly and relatively inefficient as a load carrier. It has proved of value for special services where the airplane is hopeless, such as for rescue operations, some kinds of crop dusting and, in general for regions with no roads or landing fields. It has not yet been able to compete with motor transport.

The present handicaps of the helicopter are not fundamental, and future designs may be simplified by eliminating the articulated rotor with its unfavorable vibration characteristics and limitation on forward speed from blade stalling.

It will not require inventive genius to work out the application of an autopilot to correct difficult handling char-

acteristics which now effectively prevent blind flying in slow-speed approach conditions. The future high-speed helicopter should have a payload equivalent to an airplane designed for the same speed and still retain the ability to hover.

Some mention should be made of so-called convertible aircraft, intended to operate as a helicopter at take-off and landing and to convert itself mechanically into an airplane during flight. Many schemes to accomplish this have been proposed, all involving great complication and risk, and violating most of the principles of good functional design. However, I can only echo the general of the last war, who said, when shown plans for an unusually ingenious but tricky new weapon: "Even if it works, I don't want it!" The prospect for the development of fast efficient helicopters should make such a combination vehicle unnecessary.

The evidence from current trends in research suggests that the helicopter may ultimately replace the airplane for short feeder-line flights, that turbo-propeller airplanes will serve normal intercity traffic and that transcontinental and transoceanic flights will be in very high altitude turbojet airplanes of very high speed. Six hundred miles per hour cruising speed is not unreasonable.[2]

Airplane designers might profitably use the time needed by their power plant colleagues to bring the turbojet economy and reliability to a commercially attractive standard by improving the safety and livability of airplane passenger compartments, and by solving the very critical problem of the fatigue life of the airplane's fundamental structure.

In the meantime, commercial air transport may stagnate at about the present level, due to congestion at airports attempting to handle both local and long distance flights with inadequate equipment. An international system of air navigation and traffic control is essential to the full utilization for a peaceful world of the "conquest of the air" which our generation so proudly claims.

Competition, both military and commercial, forces increased airplane performance. Improved performance has come in the past from more efficient aerodynamic forms, combined with more powerful and efficient propulsion systems and fuels. It appears from current research that aerodynamic progress in the transonic and supersonic speed regions is paralleling the rate of progress formerly achieved in the lower region. One can only conclude that the manifold advantages of exploiting the conquest of the air will ensure that the necessary effort will be made over the coming half century.

[2] Prediction of J. J. O'Connell, Jr., Chairman of Civil Aeronautics Board, United Nations broadcast, April 22, 1950.

SOME PROSPECTS IN THE FIELD OF ELECTRONICS

ACKNOWLEDGMENT

This article is another one making up the symposium "Science and Tomorrow" contained in the 125th Anniversary Issue of the "Journal of the Franklin Institute," January 1951. Written by V. K. ZWORYKIN of Radio Corporation of America, it discusses the trends in the electronics field in the near future.

The boundaries of the field of electronics, like those of almost any branch of technology, are vague. Enclosing within them everything in which the electron plays a vital function would certainly take in too much territory, yet, restricting the domain of electronics to devices involving the employment of free electrons only would leave out such items as crystal triodes and diodes which, by reason of their function, have been quite generally claimed by workers in electronics.

It must be recognized, however, that until recently the free electron has been responsible for the role which electronics has come to play in the modern world. Its extraordinarily large specific charge makes it possible to impart to it high velocities with the aid of moderate electric fields and to deflect its path with ease by either electric or magnetic forces. This is the reason for its effective use for the amplification of rapidly varying currents or voltages and the generation of high-frequency oscillations in the vacuum tube, for the indication of voltage and current variations in the oscillograph, and for the generation of picture signals in the television camera and the reconstruction of the televised scene in the viewing tube. The same property proves valuable in the detection and measurement of light by phototubes and in the generation of X-rays in X-ray tubes. Finally, in the electron microscope the scattering properties of matter for fast electrons, the nature of their interaction with magnetic and electric fields, and their wave characteristics combine to permit the use of free electrons to extend the recognition of microscopic detail by two orders of magnitude.

The history of electronics can conveniently be divided into four overlapping periods. In the first, ushered in by DeForest's invention of the audion and terminated, approximately, by the First World War, electron currents were controlled in vacuum tubes in much the same manner as a steam valve controls the flow of steam in a pipe. No more attention was paid to the behavior of the individual electrons in the tube than is customarily expended on the motion of the individual steam molecules in the valve. The English designation "electron valve" is singularly fitting for this period.

In the succeeding period, taking up much of the 'twenties and 'thirties, the directed, rather than random, character of electron motion in vacuum was applied in the cathode ray tube and for improving the efficiency of amplifier and oscillator tubes by proper shaping and aligning of electrodes. The electrostatic secondary-emission multiplier phototube, in which secondary electrons are guided from one electrode to the next by a careful adjustment of electrode shapes, is a typical product of this epoch.

The third period, beginning some time before the Second World War, further subdivided the beams of electrons into groups and dealt primarily with the latter. This subdivision was either on the basis of time, the electrons being bunched at certain phases of an applied high-frequency field as in the klystron or magnetron, or of space, as in image-forming devices; the electron microscope and the image tube are typical representatives of this group. A somewhat different form of group selection, on the basis of time and place of injection, occurs in the betatron.

The fourth period in the development of electronics, in which we find ourselves at present, is concerned with the control of electrons within solids. Here, with crystal diodes, transistors. photoconductive pickup tubes, etc., we have barely made a beginning. However, in large part with the aid of the typical products of the preceding periods, which are at the same time undergoing continuous further development, this period should prove at least as productive as any of the earlier ones.

Let us visualize some of the trends in the evolution of the electronic art in the near future. We may distinguish here between the development of new devices and the extension of their practical application. In the field of amplifying tubes and oscillators we can safely predict that the stress will continue to be placed more and more on types suitable for the very-short-wavelength region of the radio spectrum, where the time of travel of the electrons can no longer be neglected in comparison with a period of oscillation. In oscillators and narrow-band amplifiers the tube geometry will, as now, for example, in magnetrons and klystrons, be determined in large part by the frequency of the oscillation generated or amplified. At the same time, wide-band amplifying tubes will increasingly be provided by devices in which energy is exchanged between electron streams and traveling wave fields, as in the traveling-wave tube, the double-stream tube, and others. Similar techniques of energy interchange, in reverse direction, serve to provide high-energy electron beams in linear accelerators.

Concurrently, there will unquestionably be a continued great increase in the application of electronic components in all departments of life. In heavy industry case-hardening and annealing of metal parts by radio-frequency currents already plays a large role. Glueing of plywood, heat-detonation of explosive rivets, sealing of metal tubes, welding of plastic sheet, and dehydration of antibiotics are other effective uses of radio-frequency heating. In the food industry the same technique may be employed for the sterilization of packaged foods and liquids, the blanching of vegetables, and specialized cooking operations. Food sterilization by bombardment with electrons in the million-electron-volt range also appears to be a promising field. In medicine radio-frequency fields may not only be employed for certain types of therapy, but, in addition, the "radio knife" which seals the capillaries severed in an incision, is a valuable aid in surgery.

Up to this point we have considered the power output of electronic devices; of quite as great importance is their employment for analytical and diagnos-

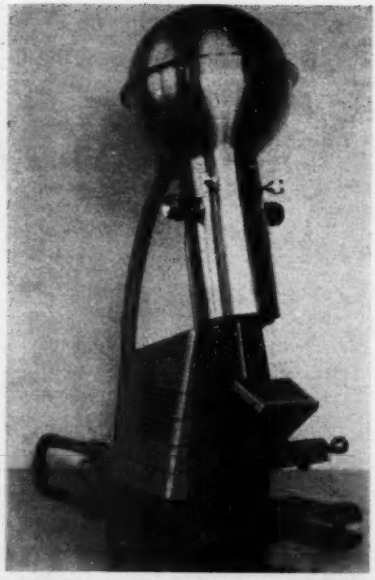


FIG. 1.—A modern desk-type electron microscope

tic purposes. The use of very-high-energy X-rays for the detection of flaws in machine parts, facilitated by electron image amplifiers, will become increasingly standard practice. Similarly, spectroanalysis of the alloys used for machines and manufactured products with the aid of automatic recording equipment employing multiplier phototubes will be much more general than it is at present. Isotope tracer methods in chemical and metallurgical studies will call for scintillation counters and other electronic equipment in increasing numbers.

The same devices will find extended use for diagnosis, therapy, and research in medicine and biology. Many time-consuming routine operations, such as the making of blood counts, can certainly be carried out more speedily and accurately by electronic methods. Television techniques applied to the study of the variation in skin potential distribution already hold much promise for the rapid diagnosis of brain tumors and heart conditions, yielding information in much more readily interpreted form than that supplied by the conventional electroencephalograph and electrocardiograph. There can be little question that the measurement of body potentials and their variation, made possible by amplifying equipment of high sensitivity, will prove of increasing value in many other areas of medical diagnosis and biological research.

The electron microscope, also, is likely to find not only increasing use as a research tool in biology, chemistry, and metallurgy, but, on the basis of research findings, as a diagnostic aid as well. The introduction of smaller, more compact, models of the electron microscope, supplementing the larger research instrument, should prove particularly valuable here, just as in routine chemical tests. At the same time, fundamental research probing into basic life processes, the growth mechanism of crystals, and innumerable other frontier regions of knowledge will find the electron microscope indispensable.

Even broader in its applications than the electron microscope is the electronic computing machine. It not only supplies quantitative answers to problems in fields governed by known laws, however involved their application may be; it also greatly accelerates the discovery of laws governing physical phenomena through the rapid comparison of the predictions of an hypothesis with actual measurements.

There are two types of electronic computing machines: the analogue computer and the digital computing machine. In the former the variables in the equation to be solved are represented by electrical quantities, such as current or voltage, and the operations occurring in it, by the characteristics of the circuit and tube elements making

up the computer. Both in principle and in function, the electronic analogue computer is closely related to the mechanical analogue calculating device, which, in the form of Bush's differential analyzer, ushered in the era of large-scale computing machines.

Examples of electronic analogue computers are McNee's differential analyzer for the solution of ordinary differential equations (*1*);[1] Goldberg and Brown's simultaneous equation solver (*2*); and the numerous auxiliary circuits employed, in radar technique and elsewhere, to simplify the presentation of data. By its very nature the application of the analogue computer tends to be specialized, its accuracy limited.[2] Even so, it has proved its usefulness in countless ways, in a saving of time and effort and the elimination of human error.

By contrast, the digital computing machines are quite universal in their application and their accuracy is only limited by the number of significant figures which can be entered on them. As the name implies, the digital computer deals with numbers represented by a sequence of digits. The primary difference between the electronic digital computer and the familiar mechanical computing machine is a difference in the speed with which the electronic machine can perform the elementary arithmetical operations. This quantitative difference, however, leads to important qualitative differences: If the time in which the elementary arithmetical operations are performed is measured in microseconds, the basic advantage of the high speed of the machine is lost unless the time of transfer from one operation to the next, also, is measured in microseconds. This necessarily eliminates the role of a human operator from all intermediate operations and even prohibits the employment of mechanical devices in the major portion of the computation process. The human operator only enters in the setting up of the machine for a given calculation and the reading of the final results.

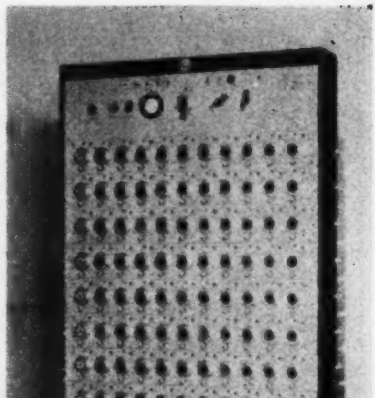


FIG. 2.—An electronic analogue computer: the simultaneous equation solver

To perform its function effectively the electronic digital computer hence requires, in addition to a group of electronic computing units, a set of "fast," electronic, memories, in which an in-

[1] Numbers in parentheses refer to references at the end of the paper.

[2] Eventually, as in the simultaneous equation solver, a rapidly converging process of iteration may be employed to achieve results of arbitrary accuracy.

termediate result can be stored until needed for a later operation, as well as a command system on which the complete sequence of operations to be performed by the machine may be recorded. Additional, "slow," memories, in the form of magnetic or punched tape, can be employed, furthermore, for the storage of large quantities of information, such as tables of functions, which may be fed into the fast electronic memories on order.

Much ingenuity has been expended in devising satisfactory electronic memories. The essential feature of all electronic memory devices is the presence of elements with two alternative stable states which are maintained indefinitely unless subjected to new electrical "writing" impulses. The Eccles-Jordan trigger circuit, containing two vacuum tubes so connected that, in equilibrium, one tube conducts while the other is cut off, constitutes such a single element of memory. More recent devices, such as the cathode-ray tube memory of F. C. Williams (3) and the SB-256 tube of Rajchman (4), by comparison, utilize the properties of the secondary emission of insulators to provide several hundred such elements (corresponding to the storage of an equal number of binary digits) in a single envelope.

The last few years have seen great advances in the magnitude, scope, and organization of digital computing machines. These will unquestionably continue and further expand the role of electronic methods in science and in our economic organization. It may well be, however, that electronic computation will achieve its greatest triumphs through the integration of analogue computing devices, with their ability to short-circuit extensive numerical calculations in specific applications, in digital computing systems. In fact, it seems scarcely thinkable that effective

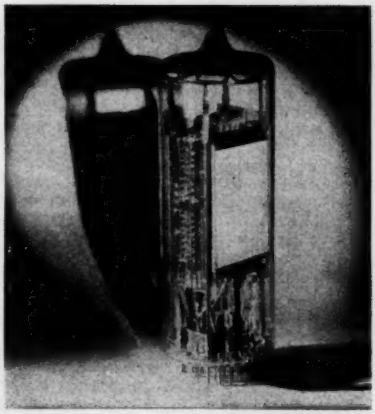


FIG. 3.—The SB-256 tube, an efficient electronic memory

headway can be made with extremely complex problems such as are encountered in weather prediction unless all available techniques are combined to best advantage.

Possibly the most striking demonstration of the power of electronics to the average man has occurred in the field of television. The development of this new industry has far outstripped the predictions of the most extravagant prophets of a few years ago. It requires little imagination today to foresee for the television set a universality comparable to that of the kitchen range or the refrigerator. Numerous articles have dealt with the probable effect of this new factor on education, social patterns, and the economy, and I shall make no attempt to add anything to their conclusions. Technically, also, the pattern for the future has in large part been established for broadcast television, with the creation of a sound basis for the smooth change-over or side-by-side existence of color and black-and-white television (5). Nevertheless, a host of interesting engineering problems whose

FIG. 4.—Size reduction and simplification in television pickup tubes: the image orthicon and the vidicon

solution will lead to the simplification and improvement of different phases of television equipment and television service remain to be solved and, to judge by the recent past, will be solved in original fashion.

There is another aspect of television development which has not received, and probably will not receive, nearly as much attention as broadcast television and which may yet, eventually, turn out to be of even greater significance. This is industrial television—the utilization of television techniques in industry, research, education, commerce —in short, in all fields apart from broadcasting. The basic industrial television system, in the form of a self-contained, cable-connected link incorporating a television camera and a combined viewing and control unit, enables the observer to transfer his vantage point to dangerous and inaccessible locations; to view simultaneously several, spatially widely separated scenes; or to share an intimate view with a large number of other observers without mutual interference. The first condition is realized, for example, in the watching of carefully shielded radioactive reactions from a protected point, the checking of engine performance by a camera mounted on the underside of an automobile chassis, or the observation of the proper filling of the scoops in strip mining by a camera placed directly above the scoop; the second, by the simultaneous observation of indicating

FIG. 5.—An industrial television system: camera and control unit

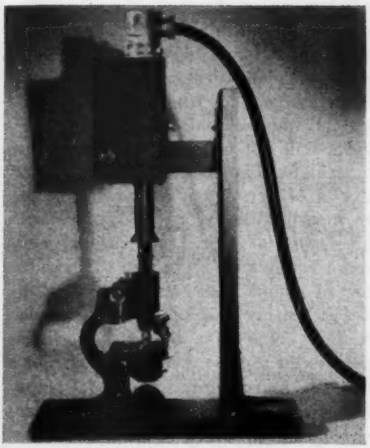


FIG. 6.—Television for the classroom: industrial television camera mounted on a microscope

instruments at a number of substations from a central station; and the third, in the watching of surgical operations on television receivers linked to a camera mounted above the operating table or the presentation of microslides at high magnification to groups of students; in the last instance the microscope image is projected directly on the target of the pickup tube in the television camera and the enlarged image is either viewed directly on a home receiver or projected on a screen by a theatre projector.

In all these instances compactness and simplicity of the television camera is an essential requirement. A great step forward in this direction has been the recent development of the vidicon (6), a highly sensitive television pickup tube with a photoconductive target. This tube, though only 1 in. in diameter, is capable of transmitting high-quality television images at moderate light levels. Furthermore, the extraordinary simplicity of the vidicon simplifies control of the camera from a distance: In a typical example of present industrial television equipment (7), the control unit incorporating a monitoring kinescope is connected by a 500-ft cable to the camera. This cable not only transmits the video signals from the camera to the kinescope, but, in the opposite direction, transmits electric power and centering, focusing, and deflection signals from the control unit to the camera.

The small dimensions of the new camera tubes also lend themselves well to their employment in color television cameras transmitting simultaneously picture signals for the three primary-color components of the picture. Perhaps of even greater value in many practical applications is the observation of objects in three dimensions, made possible by the employment of a stereo television camera. Here two vidicon tubes, with a pair of objectives controlled by a single focusing movement, are mounted side by side. In viewing the stereo receiver linked to the camera, the eyes of the observer are in effect translated to the position of the two stereo camera objectives—and, at the same time, endowed with the greatly increased focusing range or "accommodation" of the latter.

An example where such three-dimensional observation is particularly valuable is the presentation of surgical operations to medical students. Here the relative spatial position of the surgeon's tools, the incision, and the organs on which the operation is performed is of primary importance. The same applies, of course, also wherever television is employed for instruction in mechanical operations. The immediacy and flexibility of television demonstrations as compared, for example, with demonstrations by means of motion picture film should render them an exceedingly effective aid in the process of education.

In the development of networks of television broadcasting stations we have

witnessed the use of micro-wave links paralleling that of coaxial cables. In industrial television, too, situations arise which can only be met by the use of such links, even though this materially complicates control problems. Examples are the transfer of visual information from the ground to aircraft and *vice versa*, for example, as an aid to navigation, the transmission of scientific data from rockets, and the sending of astronomical information from balloon-mounted telescopes at a sufficiently high altitude to escape major atmospheric disturbances. The extraordinary range of applications of television is best realized when it is recognized that television does for the sense of sight what radio and the telephone have done for the sense of hearing. Insofar as the amount of intelligence acquired by the average person through vision is incomparably greater than that acquired through hearing, we can safely predict that the revolution wrought in our lives by television in its various forms may materially exceed that brought about by the development of means for auditory communication.

As I have already mentioned, the most recently developed television pickup tube, the vidicon, employs a target consisting of a photoconductive material, that is, a material which conducts electric current under the influence of light. Employed in a simple photosensitive cell, such a material does not emit free electrons into space and hence does not fit into the realm of "electronics" in the narrower sense. Yet, materials from the larger family of the semiconductors, to which it belongs, are playing an increasing role in electronic apparatus—not only as components of tubes utilizing electron beams, such as the vidicon, but also quite apart from vacuum devices in the form of the crystal rectifier and the transistor they fulfill certain requirements previously met only by vacuum tubes.

Whereas, at present, there is little reason for expecting wholesale replacement of vacuum tubes by their semiconductor equivalents — certain basic shortcomings of the latter militate against this eventuality—the crystal elements will not only find increasing use in specialized apparatus where compactness is of primary importance but also be incorporated more and more into the design of more conventional electronic equipment. Here also the trend is toward compactness, as exemplified by the increasing use of printed circuits. In this connection the crystal diodes and triodes represent but one phase of a constant search for improved components for electronic apparatus. From another point of view, the intensive preoccupation with the properties of the solid state, which has led to their discovery and development, is creating a fund of knowledge which has already borne rich fruit in the development of efficient phosphors, ferromagnetic materials, and crystal counters. This is bound to contribute materially not only to the electronic industry, but all other industries as well, and to supply effective new tools for scientific investigation. Whatever the future of electronics may be in the ensuing half century, it is certain to profit from fundamental research as it has in the past and to repay

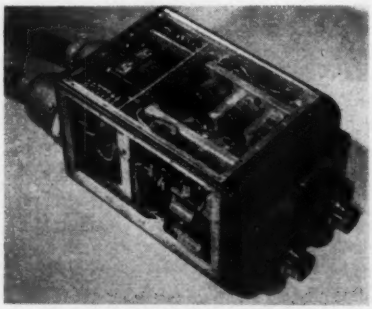


FIG. 7.—Stereo television camera for conveying three-dimensional images

its debt generously in the form of instruments and methods to carry out the tasks of research.

In the past half century electronics has demonstrated its ability to annihilate distance for both sound and sight. In countless ways it has aided human safety and relieved man of routine efforts. To the scientist it has proved itself an indispensable aid in research. No prophet is needed to state that, in the future, the application of electronics in these fields will be even wider, its usefulness even greater; more than that, as the past amply shows, no prophet can have sufficient imagination to predict, at the present time, just what forms these further applications, this increased usefulness may take. Yet one thing is certain: In the future as in the recent past electronics will cooperate with the other branches of science and technology to achieve the satisfaction of physical needs, the extension of human knowledge, and the freeing of man's spirit for creative effort.

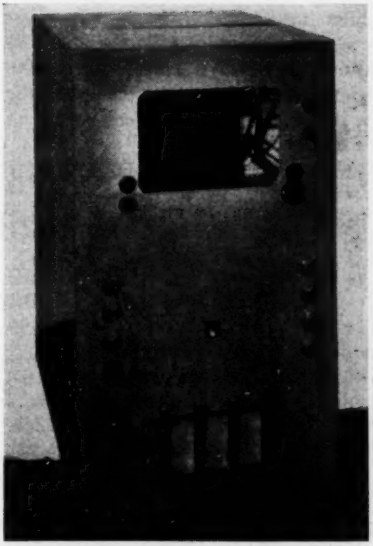


FIG. 8.—Stereo television receiver: polaroid screens in front of the two viewing tubes and in front of the eyes of the observer make one image visible to each eye

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FUTURE DEVELOPMENTS IN TRANSPORTATION

ACKNOWLEDGMENT

This article by CHARLES F. KETTERING of the General Motors Corporation is one of a series contained in the symposium "Science and Tomorrow," printed in the 125th Anniversary Issue of the "Journal of the Franklin Institute," January 1951.

In considering future developments in the field of transportation, it is only natural to focus attention upon the automobile; for, at least in this country, people travel far more miles by automobile than by all other forms of transportation combined. We obtain a little greater appreciation of the tremendous amount of motor vehicle travel when we note that annual passenger car mileage is about 330 *billion* miles, as compared to 0.5 billion for passenger trains and 0.4 billion for our domestic airlines. From past experience, it appears that this figure of 330 billion is merely a transient point on a curve which as yet shows no sign of leveling off.

AUTOMOBILE TRANSPORTATION

Now for me, or any other man in the automobile business, to predict specifically what the motor car of the future will be like, what changes will be made in each part of the engine, what kind of transmission, rear axles, etc., the future cars will have is obviously an impossibility. I can tell you, however, that the car of the future will be better than the cars you see today, because it is impossible for an industry as great as the automobile industry to stand still. If a committee of experts selected the most advanced model and put it in a glass case to protect it from wear, that car would be just as much out of date ten years from now as a ten-year-old car is today.

One feature of the automotive business not always recognized by the public is its relationship to progress in other fields. The automobile isn't simply the product of a single industry—it is the product of many industries. It moves ahead as the result of new discoveries and developments in the rubber industry, in the steel industry, and in the petroleum industry. It moves ahead as the roads you drive on improve, or as the manner in which the public wants to use this piece of transportation machinery changes from year to year.

Basically, the automobile of the future will be whatever the public that uses it wants it to be, limited only by the ability of the industry's hard-working

scientists and manufacturers. Each technological advance permits us to incorporate more new features and ideas into the product; the customer then indicates which of these features will be retained. This has been true since the inception of the automotive age, and will continue so long as the industry is free to retain its present highly competitive nature.

Today's automobiles perform as they do largely because the customer has selected this particular combination of features. Why can't we build cars to give 50 miles per gallon? The answer is that we can. But we couldn't sell them, because today's motorist demands more acceleration, higher speed, and greater riding comfort than can at present be incorporated into such a vehicle. Each manufacturer is striving to provide that combination of performance, fuel economy, handling and riding qualities, and initial cost which will be most attractive to the buyer. All of which comes back to the fact that the manner in which the buyer wants to use his car determines how it will develop in the future.

With these general thoughts in mind, we may wish to take a little closer look at the situation and see what conclusions might be drawn from our previous experience.

Car Performance—In the first place, it seems unlikely that top speeds will be increased to any great extent. Most of us can recall when one of the first questions the prospective buyer put to the salesman was "How fast will she go?" We seldom hear this question now, and the fact that today's cars will go about as fast as most people want them to is confirmed by comparing the present maximum speeds to those of ten years ago. Such a comparison reveals that the 1940 models had substantially the same top speed as those of 1950, the increase being less than 5 miles per hour in most cases.

The trend toward better acceleration and hill climbing ability which was quite pronounced prior to 1940, has leveled off during the past ten years. Part of this leveling off was due to lack of further development during the war; another factor was an increase in car weight, which served to balance out the improvement in performance which would otherwise have been obtained. The new-car buyer is keenly aware of car performance, and we will probably see some increase in this quality in the cars of the future. However, a few of our present vehicles already have sufficient power to spin the rear wheels on concrete, and it is unlikely that the performance of these cars will be increased to any great extent. Other models with smaller engines will continue their trend toward more power, but even these cars will feature increased fuel economy.

High Compression Engines—As indicated previously, performance and fuel economy are opposing factors, and optimum conditions for one are achieved only at a sacrifice of the other. However, any increase in over-all efficiency may be used to improve either or both of these quantities. Now there are many things which may eventually be perfected so as to give us greater efficiency, but the most important, and the one most likely to yield the greatest future gains, is the engine. These gains will be obtained by using engines having higher compression ratios.

Engineers have long known that the key to higher efficiency in internal combustion engines is in increasing the compression ratio. In the past, attempts to utilize this important principle in spark ignition engines were largely limited by the quality of the fuel available. As a result, the engineer has been able to increase compression ratios only as rapidly as the petroleum industry could increase the octane rating of their gasoline. Past progress is illustrated by

comparing compression ratios of twenty-five years ago to those of today. At that time they were about 4.5 to 1; today the average compression ratio is 7 to 1. This increase was, of course, made possible by the development of high antiknock fuels. Coupled with other engine improvements, it has enabled today's car owner to save one-third the cost of his fuel as compared to the owner of twenty-five years ago. This one-third better fuel economy saves the public over a billion dollars each year.

The production of high antiknock fuels was greatly stimulated by the demands of our Air Force during the war, and it was apparent that fuel quality would permit a marked increase in the compression ratio of postwar cars. However, existing engines were approaching the point beyond which further increases in compression ratio would be limited by engine characteristics rather than by fuel detonation problems. Fortunately, our people were well aware of this situation, and had already set out to do something about it.

As frequently happens, one of the first things we had to do was to disprove what some engineers had accepted as a basic truth—that it would be impossible or at least impractical to build an engine which could operate smoothly under the high loads encountered with high compression ratios. We felt certain, however, that it would be worthwhile to thoroughly investigate the problems and possible benefits of engines having compression ratios up to twice as high as those then in production.

Our first studies were conducted with single cylinder laboratory engines, using triptane, a very fine fuel which we produced for the government in a small scale pilot plant during the war. Triptane has a knock rating far above 100 octane fuel, and permitted us to run our single cylinder engines at compression ratios in the range of 15 to 1.

Out of this single cylinder work came sufficient encouraging data to warrant building a six-cylinder high compression engine for testing in a standard production Oldsmobile. Our single cylinder studies had indicated that a good compromise between high compression problems and benefits was obtained at a ratio of about 12.5 to 1, and this ratio was used in designing the new engine. Rather conventional design procedures were followed except that all components were made more rigid so as to carry the higher loads imposed. In addition, engine displacement was set at a rather low value, so that the developed horsepower would be comparable to that of a standard Oldsmobile engine. This enabled us to present a very practical demonstration of its smoothness and general performance.

To do this we used two identical cars, one the standard production model and the other containing the new engine, and asked various engineers to drive first one car then the other. Since each engine had about the same horsepower, it was evident that there should be no appreciable difference in over-all performance. The test would, however, reveal any tendency toward roughness, sluggishness, or whatever other flaw the driver might be expecting to find in the new engine. Those who drove the car confirmed our statements that the two engines behaved about the same.

The real progress which the engine represented, and which could not be observed by test driving the car, was its greatly increased fuel economy. A check of the constant speed level road economy of the two cars showed that, under these conditions, the high compression car gave from 35 to 40 percent better economy in miles per gallon than the standard car. Although these data were important from an engineering standpoint, they gave only part of the story, because automobiles are not driven on level roads at constant speed

very much of the time. Approximately two-thirds of the gasoline is consumed in city driving where a large percentage of the operation is transient and requires the entire throttle range of the engine.

In order to determine the economy gains under more typical driving conditions, a number of cross-country trips were made in which both cars were driven together at the same speed through the same traffic. On a large number of such trips under widely varying road conditions the average gain in economy was about 33 percent, although under some conditions gains approaching 50 percent were obtained. Several extended trips made entirely in city traffic showed gains of over 40 percent, which is of major importance in view of the large quantity of fuel burned under these conditions.

The important thing to remember about all this is that these gains were obtained under actual driving conditions, and that high compression engines are completely suitable for mass production. So this thing of greatly increased economy through high compression ratios is not just an impractical experiment in a research laboratory. These very large gains, which become simply enormous when we consider the millions of passenger cars manufactured each year, will be available to the motoring public as soon as the petroleum industry can supply large quantities of fuel with a sufficiently high antiknock value.

How soon will that be? Well, let's say it all depends. In the first place, it depends on the rate at which the octane rating of commercial gasolines can be increased. Upgrading the fuel is the most obvious way of solving detonation problems, and the public's current interest in and purchase of advanced engines requiring the very best fuels which are available today have served to spark the race among petroleum refiners to develop better fuels.

A second consideration is just how high an octane rating will be required for the satisfactory operation of a production 12 to 1 engine. Fortunately, this fuel-engine relationship has two sides, and the automotive engineer will be able to contribute mechanical octane numbers which are just as effective as the chemical octane numbers produced by the petroleum industry. For example, increasing the compression ratio of a certain engine by one ratio (e.g., from 7 to 1 to 8 to 1) might require that we increase the quality of our fuel by about eight octane numbers. Therefore, if we could take the engine which now operates at 7 to 1 on a given fuel, and redesign it so that it would operate at 8 to 1 on the *same fuel*, we would have built the equivalent of eight chemical octane numbers into the engine. In describing this gain, we say that we have added eight mechanical octane numbers to the engine.

With our previous tests having already demonstrated the vast savings in fuel costs and natural resources which lie just ahead of us, we are working hard and making good headway in locating possible sources of these mechanical octane numbers. So far it appears that the most fertile field is in combustion chamber design, and our prospects along this line look very encouraging.

Although we cannot manufacture our 12 to 1 engines this year or perhaps not even next year, we can build engines capable of utilizing the best fuel available. At the present time there are in production three engines, operating at about 7.5 to 1 which may be readily modified to operate at succeedingly higher ratios until they have reached the 12 to 1 figure. It seems certain that other engines introduced in the future will follow a similar pattern, to facilitate obtaining the maximum possible benefit from the continual technological advances of the petroleum industry.

Automotive Gas Turbines—In the last year or so two turbine-driven vehicles have received considerable publicity, so it might be well to comment on the probable future of automotive gas turbines.

The British Rover passenger car and the Boeing truck installations have both demonstrated that such vehicles can be propelled by gas turbine. This point has never been questioned. The question, of course, is whether such machines can be made competitive with our present automobiles and commercial vehicles.

Among the advantages claimed for the gas turbine are high starting acceleration, the ability to use a wide variety of fuels, simplified ignition and lubrication, and less vibration due to the absence of power impulses. These advantages do exist, but in obtaining them we inherit several knotty problems.

For example, to obtain the high rate of acceleration reported, the driver of the Rover car was required to hold on the brakes, run the gas generator up to near rated speed (40,000 rpm.) and then release the brakes, at which time the stop watch was started. The acceleration from idle (7000 rpm. on the gas generator) on the other hand was reported as being rather slow. Moreover, neither the Rover nor the Boeing engine has a power unloader or neutral position. This is equivalent to having an automatic transmission locked in the drive position at all times. The addition of an unloader or by-pass between the gas generator turbine and the power turbine is not impossible, but will certainly result in a more complicated control system.

One of the most serious limitations is the fuel consumption of these units. Although they will operate on kerosene or diesel oil, present consumption is more than twice that of a piston engine of equivalent power. It is expected that this will be improved through the use of regenerators, which will, however, complicate the space problem. The basic turbine is generally a small, compact unit, but the installed turbine with its bulky ducting is not a space saver.

Further handicapping the turbine for vehicle use is its high idle fuel consumption, since it appears that the automotive gas turbine may be expected to use one-fifth as much fuel at idle as it would at full throttle. There does not appear to be any ready solution for this problem.

Another difficulty is the lack of braking power provided by the turbine. Lifting the accelerator pedal gives a free-wheeling sensation at high speed, indicating that present-day brakes would have to be markedly improved or some auxiliary braking system developed. Similarly, intake and exhaust noise would have to be reduced without using overly large silencers. These problems are not insurmountable, but serve to emphasize the many related or side problems created by the turbine characteristics.

Work in the turbine field is progressing rapidly, and although it seems unlikely that turbines will be used to drive cars and trucks in the foreseeable future, no one can say it is impossible. Should future developments make the turbine competitive, it will almost certainly first appear in trucks and busses, since functional design can be carried out to a greater degree in these installations.

Perhaps we may best sum up the turbine's future in road vehicles by suggesting that it may one day supplement diesel and gasoline engines but is not likely to replace them. In each case the turbine must prove that it is not only equal to but is better than the engines which are now providing such dependable service.

Other "New" Engines—Today, as always, a few people are experimenting with other engines markedly different from those now in use. Some of these designs incorporate relatively new ideas, while others attempt to make practical designs previously discarded as unworkable. However, we do not expect the present poppet valve reciprocating engine to be replaced for many years to come. Its compression ratio will definitely be increased; no doubt further refinements will appear in carburetors, ignition systems, head design, manifolding, etc. But the basic operation of the automotive engines of the next fifteen to twenty years will probably be the same as those of today.

Automatic Transmissions—Certainly the most revolutionary change in the industry in many years has been the recent widespread adoption of completely automatic transmissions. The first of these transmissions was introduced in 1940, but, largely because of the war and the attendant reconversion problems, there were still relatively few on the road at the end of 1947. About that time other manufacturers began to offer this driving convenience, and at present automatic transmissions are being produced at the rate of well over one million per year. This figure is still rapidly increasing, and it is likely that within five years a large majority of all cars sold will be so equipped.

RAILROAD TRANSPORTATION

Most of us have relatively infrequent contact with the railroads, so it is only natural that we are more aware of progress and changes in automobiles than of advances in rail transportation. However, almost any improvement in railway equipment is certain to benefit all of us, irrespective of the number of trips we make, for how many things which we use each day have not at one time or another been transported over the rails which serve to integrate the various segments of our complex economic system?

Today the railroad industry is in the intermediate stages of a truly remarkable technical revolution—the replacement of the steam locomotive by the diesel-electric. I say "remarkable" with reason, for in less than fifteen years after its introduction, the high-speed diesel obsoleted an engine which had been used and perfected for more than a century. Part of the rather spectacular story of the diesel locomotive is told by the figures in the following table. These statistics appeared in the May, 1949, issue of *Diesel Power and Diesel Transportation*, and show the number of each type locomotive in service, by years, for Class I railroads (Class I roads are those with an annual gross revenue of over $1,000,000).

STEAM AND DIESEL LOCOMOTIVES IN SERVICE—CLASS I RAILROADS

Year	Steam	Diesel
1929	56,936	22
1939	41,117	510
1943	39,725	2125
1947	35,108	5772
1949	32,613	7201

It should be pointed out that the 22 diesels in service in 1929 were old style cumbersome engines, saddled with the same high weight-to-horsepower ratio which had always severely limited applications of the inherently efficient diesel. We had begun to work on this weight problem about 1928, and by 1934 had developed an engine which found quick application in the first light weight streamlined diesel locomotive, the Burlington *Pioneer Zephyr,* whose maiden run in April of that year was to usher in the development of a completely new industry.

Little more than a month after its inaugural run, the *Pioneer Zephyr* gave a spectacular demonstration which foretold the shortened schedules soon to appear on the main line routes. This was the now famous Dawn-to-Dusk run, in which the *Zephyr* clipped nearly 13 hours from the fastest scheduled steam time between Denver and Chicago. Since that time, the fast schedules and punctuality of diesel passenger service have become familiar to all of us, and these shortened schedules in themselves might well have been sufficient reason for the adoption of this new power source.

Not so widely appreciated, but even more important, is the improved operating economy of the diesel. The overall thermal efficiency of this engine is in the order of 32-38 percent, whereas the simple steam engine has an efficiency of about 6 percent. Although diesel fuel is more expensive on a BTU-per-dollar basis, the marked difference in engine efficiencies permits the diesel to operate with a fuel cost of a little more than half that of the steam engine. Further savings result from reduced maintenance costs, modern diesels requiring far less attention than do their steam counterparts.

Consequently, the immediate future of railroad transportation may be summed up in two words—further dieselization. Today there are on order no steam passenger locomotives and only a very few steam freights and switchers, these orders having been placed largely for reasons other than the performance and operating cost of the engines themselves. The greatly reduced operating cost of the diesel is encouraging the railroads to accelerate the replacement of their present steam engines to the greatest extent possible, and already a few roads have become completely dieselized. It is at this point that still more savings are effected, with the elimination of water columns, pump stations, coaling stations, and other costly supporting services. For example, one road, now completely dieselized, had been spending $70,000 per year in fire claims and in maintaining fire patrols to combat grass fires caused by steam locomotives. Moreover, the higher availability of the diesel engine permits a fully dieselized road to operate with fewer locomotives. The greater availability of the diesel is apparent from the preceding table, which shows that 7000 diesel locomotives have replaced 24,000 steam engines during the last twenty years, in spite of a 50 percent increase in both passenger miles and ton-miles of freight during this same period. Still other economy factors are a reduction in locomotive water required, and a saving in track maintenance expense, since diesels are known to cause less damage to road beds and trackage than do the reciprocating steam engines.

The Diesel Rail Car—It is fortunate for the railroads that the diesel was freed of its weight shackles as early as it was, for it has been the speed, cleanliness, and comfort of the diesel streamliners which have enabled the railroads to compete with other forms of modern transportation. Although the main line passenger runs are, in general, profitable operations, the industry has for many years reported a large number of local

or short line runs in red ink. This deficit has been largely the result of high operating expenses and few passengers. But a new application of the diesel engine—the diesel rail car—introduced in May, 1950, gives promise of switching these annual losses to the profit side of the ledger.

Of course, rail cars aren't new at all, having been used even before World War I, but heretofore no one had built one using a modern streamlined car and modern diesel engines. The two new air-conditioned units now serving New England commuters are a far cry from the old distillate-burning rail cars, and a refreshing improvement over the dingy, rattly coaches serving many commuters today.

The technical features of this completely self-contained one-car train are of interest in that new techniques are employed in order to insure satisfactory performance. Subway-type electric controls regulate twin 275-horsepower diesels, whose power is transmitted to the wheels through specially designed hydraulic torque convertor transmissions. The cars may be operated singly or in multiple. Four types of interior arrangement are available to satisfy various passenger-baggage requirements, thus giving additional service flexibility. Top speed is 83 mph., with most efficient operation obtained at about 70 mph.

How successful the diesel rail car will be is still a debatable question, but its qualities seem to fit the type of service for which it was designed very well. The previously discussed operating advantages of diesel locomotives likewise hold true for the rail cars, and the relaxation permitted by the pleasant, comfortable surroundings should prove most attractive to the traffic-conscious suburbanite, as well as to other short-distance travelers.

Railway Gas Turbines—As in the case of the automotive industry, there has been considerable speculation as to the applicability of the gas turbine to the railways. The simplicity of the turbine plant (which, if perfected, could mean long periods between overhauls), coupled with its ability to use very low grades of fuel, have been strong selling points for the expenditure of millions of dollars for further turbine research and development work. Already a 4500-horsepower gas turbine-electric locomotive has been built and subjected to hundreds of hours of laboratory tests, and is now providing operational data by serving as a freight locomotive on one of our western roads.

Many of the limitations which handicap the turbine for automotive service are also encountered in railway applications. For instance, the inherently low thermal efficiency of the turbine is an ever-present stumbling block, the greatest hope for improvement in this respect resting in the hands of the metallurgist. No doubt improvement in design can help somewhat, but the development of better alloys—thus permitting operation at higher temperature—seems to be the key to higher efficiencies.

Another condition common to both automotive and railway power plant operation (and one that is a headache to the turbine designer) is the large amount of part-load operation involved in each case. In comparing the load *vs.* efficiency curves of the two engines, we find that the diesel's efficiency is fairly constant over a large range of load, whereas that of the gas turbine tends to peak up rather sharply at one particular load. This, of course, comes back to what we have previously mentioned in connection with automotive usage of the turbine; that is, the turbine's fuel consumption at light load is a large part of its full-load requirement. The seriousness of this drawback will naturally vary with each particular railroad application, obviously being greatest in switching and mountainous operation.

In looking into the future of the gas turbine, we should always keep in mind the need to correlate power plant characteristics with those required by the job. The characteristics of the ideal railroad engine are approximated to a much greater degree by the diesel engine than by the gas turbine. Consequently, if the turbine is to come into widespread use, it must become so attractive from a maintenance and low-cost fuel standpoint that the railroads will be willing to accept the natural limitations of the turbine proper. In this connection, I might point out that the railroad diesel enjoys its present dominant position because it represents a *very great* improvement over the steam engine. Had this improvement been only moderate, it is highly unlikely that the railroads would have abandoned their then-satisfactory steam locomotives and have made the extensive maintenance and operational changes necessitated by the adoption of a completely new locomotive. Today, it is difficult to foresee the gas turbine offering a similarly great improvement over the diesel engine, and it is evident that the railroads are not going to be faced with demands for an extra fireman on gas turbine locomotives for a long, long time.

SUMMARY

Nearly all prognostigators, from the fellow who buys a $2 ticket on *Blue Boy* to the financial policy-makers of government and business, base their final conclusions upon past experience. Properly tempered (and herein lies the success or failure of the prophet), this is a completely logical procedure, and is especially applicable to engineering trends, for most of our technical progress has been achieved through a process of evolution.

Thus, one of the best ways to gain an insight as to the direction in which we're going is to note our present position and to review how we reached it. In the preceding discussion, I have tried to cover a few specific phases of our transportation future in just this fashion, in order to emphasize that we can expect tomorrow further applications and extensions of the things we are working with today.

MATERIALS

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The author of this article is WALLACE R. BRODE of the National Bureau of Standards. The paper is one of a series comprising the symposium "Science and Tomorrow," published in the 125th Anniversary Issue of the "Journal of the Franklin Institute," January 1951. It discusses future trends in materials.

INTRODUCTION

In his presidential address before the American Chemical Society meeting, September 9, 1950, Dr. Ernest H. Volwiler discussed the difficulties involved in making predictions of the future in science.

Dr. Volwiler said, "Of prophecy I shall be most cautious, for the affairs of man lack the rigid controls which one can apply to a scientific experiment in the realm of inanimate chemical or physical reactions. Where the research scientist himself becomes a part of the experiment he is seeking to perform, we know all too well the great variation and the unpredictability of the results. So it is with the world where all living men are part of the gigantic, ever-changing experiment we call civilization."

He also quoted from the American Chemical Society presidential address of Dr. Harvey W. Wiley some fifty years previous, in 1901, in which Dr. Wiley, in his address on the "Dignity of Chemistry" undertook to predict the state of the science in chemistry in 1976 (which year would mark the centennial celebration of the American Chemical Society).

Dr. Wiley considered in his prophecies the material and population situation and changes expected in the following 75 years. To the extent that a mathematical calculation of reasonable certainty could be made, it is obvious that some of his predictions are reasonably accurate, but where the mind of man could influence the normal course he was often wrong, sometimes to the extent of overoptimism and sometimes he underguessed to the extent that what he predicted for 1976 took place in 1926 and now we are many times beyond the original estimate.

Dr. Volwiler has pointed out that there are often extensive errors of markedly over and underestimating in scientific forecasts, "for where basic fundamental knowledge is at hand the application of that knowledge has the tendency to come faster than one may anticipate. Where the basic facts of a given field are not at hand, however, forecasts frequently become fantasy and often take far longer than one might predict."

Among the predictions of Dr. Wiley was that this country should have a population of 225 million, which will probably be reasonably near correct

considering the increase in the past 50 years. This, however, was something that could be extrapolated from known previous data with only little chance of an appreciable error. Dr. Wiley felt that by 1976 this country would have an annual governmental budget of $4,000,000,000—which he greatly underestimated—and that there would be at least 10,000 members in the American Chemical Society. Actually there are now, after 50 of the 75 years have elapsed, over 60,000 members. This enormous growth of science beyond the predicted or expected growth is the cause of our concern about exhaustion of available material and the anticipation with which we now look for new and almost undreamed-of materials.

It would appear from experience with earlier prognostication that there are three types of predictions: *(a)* those which are reasonably obtained by extrapolation from data in the past and present; *(b)* those which are normally of type *(a)* but are disturbed or distorted by the unpredictable factors of the future; and *(c)* those which are essentially the results of unpredictable factors and bear little or no relation with existing procedures or knowledge.

Population changes are obviously an example of the first *(a)* predictable changes. Numbers of scientists working in a given field are examples of the second *(b)* type where there is a known expectation coupled with expected expansions or contraction due to the unpredictable demands. Such developments as atomic energy, television, jet planes, and metallic aluminum are examples of the third type *(c)* where sufficient data were not available at the time of prediction to have made even an approximate estimate of future conditions. In our discussion of materials we will make some attempt to consider predictions in the *(a)* and *(b)* groupings as indicated above.

Material shortages in both war and peacetime have emphasized the need for conservation of our resources and the development of new or substitute synthetic materials. Shortages of such simple and important materials as water and iron have begun to affect markedly our planning and economy. Efficient utilization or recyclization of materials into our system of usage may alleviate the shortage but this is not sufficient in many cases, and we must seek substitutes and synthetic products to take the place of diminishing natural resources.

The many directions in which our modern technology has tended to grow and develop make it exceedingly difficult to predict the materials of the future except by extrapolation of recent development. We must, however, definitely eliminate the feeling that still exists in many areas that natural products are superior to synthetic products. In general we have been able to improve on a great many substances which are considered "natural" and there is some difficulty in differentiating between synthetic and processed materials.

We may expect that materials of the future will be gradual improvements of the existing materials through continued research in production or development, or radical departures from our existing material due to shortages or discovery of better substances. We may expect that modern research methods will provide a continuous supply of new materials and that fantastic predictions made now as to future materials will in time to come appear to be ultraconservative.

As an example of the change of materials, one might consider the changes in optics produced by new lens materials —plastics have provided precision casting with optical surfaces for lenses, prisms and gratings. A recent announcement indicates that synthetic sapphire has been produced in size and quantity

sufficient to produce motion picture camera lenses. The sapphire is water-clear in appearance, has a high index of refraction and a low dispersion which permits lens production with a minimum of necessary correction for color and lens curvature. Its hardness guarantees a continued lens surface of satisfactory clarity; in fact the finished lens could be cleaned with steel wool with as little abrasion as our present day glass lenses receive from an application of soft lens tissue.

Synthetic mica has recently been successfully produced at the National Bureau of Standards; other laboratories have also indicated work on this and other similar insulating materials. The economy of nations has often been disturbed by new material substitutes—such as the effect of nylon and rayon on Japan, and some consideration must be given to the influence of a synthetic mica or mica substitutes upon the economy of India where natural mica has been one of its principal industries. India has in previous years had its economy disrupted by the development of synthetic indigo and alizarin. We recognize that the perpetuation of the old order of supply and material by propaganda of superiority of natural products over synthetic, as well as by legislation and trade treaties is not conducive to the general world advancement and an acceptance of a change in national economy and industry to conform to progress is often essential.

Our consideration of the materials of the future must be predicated on the present change in materials and an extrapolation along the general direction they are taking. We will briefly consider some of today's material advances in inorganic, metallurgical and organic substances so as to effect this perspective of the future.

Magnesium may be expected to be in a reasonably steady supply for a long period to come, due to methods of production from the nearly limitless quantities of sea water, and in a like manner bromine, which is also extracted from sea water, will be in constant supply. Other materials such as iron and petroleum seem to oscillate in apparent supply as a result of a demand rate which appears to be depleting the reserves on one hand and on the other hand the discovery of new deposits, such as the iron deposits in Labrador and Venezuela, which change the apparent critical balance of resources and demand. The development of new uses and applications of materials may markedly change the supply condition. Beryllium supplies, for example, were seriously threatened by the sudden demand for beryllium type phosphors in fluorescent light, but as often occurs in such cases, the continued research of scientists provided sufficient or better substitutes which did not use beryllium and the toxic properties of beryllium which had not been seriously considered until this wide commercial application, have together led to almost complete elimination of these phosphors and the conservation of this element for other specialized applications.

GLASS AND SYNTHETIC CRYSTALS

Glasses which are photo-sensitive and electrically conducting have recently been developed. Important progress is also being made in the less obviously significant optical glasses. Glasses composed of the rare earth oxides, phosphates, fluorides, and even sulfides, selenides and other non-oxides are being actively investigated to discover combinations that will afford highly desirable properties such as high refractivity with low dispersivity, or high transmissivities outside of the visible region. Modern fundamental research on the

constitution of glass has given extremely valuable assistance to this strictly developmental job.

There is a growing demand for large discs and lenses with very stringent requirements for optical quality. Large windows for supersonic wind tunnels are needed so that accurate observation of shock patterns and flow lines can be made by the "schlieren" and interferometer methods. Large lens elements for aerial photography, photogrammetry and for special astronomical observation are sorely needed. The trend in production is away from the conventional clay-pot melting toward the small continuous tank with non-corrodible refractory lining. In this way contamination of the very pure batch materials is avoided and uniformity of glass composition is assured by adequate stirring of the molten materials during passage through the tank.

Mention has already been made of the production of synthetic sapphire and mica. As often happens, the synthetic production can be controlled or varied so as to produce superior material as compared with the natural product. The synthetic mica has been shown to be superior to natural mica in its resistance to high temperature effects.

Synthetic asbestos will certainly be a product of the near future and the commercial production of crystalline rock salt, sylvite, fluorite, quartz, and thallium halide crystals of considerable size and clarity have opened up new fields of physical research and optics. Synthetic crystals of Rochelle salts and other materials have formed the basis of our controlled frequencies in radio transmission.

Synthetic titanium dioxide crystals, while not as hard as the natural diamond, possess nearly equal brilliance. Their application has principally been in jewelry, but in view of the easily available raw material it is certain that it will become an important optical material of the future. We may expect many new inorganic combinations in the form of synthetic crystals and amorphous glasses which will have important research and industrial uses in the future.

Barium titanate crystals in thin wafer form show remarkable electrical properties under stress, which have provided the basis for new microphone and record player sensitive elements.

CERAMIC COATINGS

As in other branches of technology, the most spectacular material advances in the field of the non-metallic, inorganic mineral products have been those related to communication, transportation, and ordnance.

In pottery and porcelain, the two notable contributions have been, (1) the development of ceramic capacitors of high-dielectric constant and low power loss for very compact radio and radar installations, and (2) oxide porcelains extremely resistant to high temperatures and thermal shock for use as turbine blades and flame throats in jet and rocket motors. The very remarkable dielectric properties of some of the titanates of the alkaline and rare earths are being utilized for capacitors by an ingenious combination of extremely thin discs, each disc varying slightly in composition so that the whole provides a material with a high dielectric constant over a wide temperature range. A combination of refractory oxides prepared by the National Bureau of Standards consisting of a large percentage of beryllium oxide with smaller amounts of alumina, zirconia and lime showed such promising properties in the labora-

tory that its fabrication into turbo-jet blades was sponsored by NACA and in full-scale test on a test stand showed by far the greatest potentiality for use of any ceramic blade developed to date.

The increased demands for power in jet, rocket and internal combustion engines have called for operation at higher temperatures. Metals for such installations must not only have the toughness and strength but must also have the high melting point necessary. Unfortunately, the metals available in the requisite quantities necessary, notably molybdenum, are highly susceptible at operating temperatures to oxidation and other forms of corrosion. By research work at the National Bureau of Standards the principle of successful application of a ceramic protective coating has been indicated and the protective coating itself has been successfully developed and applied. The coating is a metal-ceramic combination. During heating to cement the coating to the base metal, the metal powder incorporated in the mixture is welded by diffusion to the base metal, providing a firm and very adherent intermediate layer. An additional all-ceramic outer layer provides additional protection.

LIGHTWEIGHT AND PRESTRESSED CONCRETES

Lightweight concretes are now being made by three different methods. The most widely used method is that of substituting lightweight aggregates for the more common aggregates, sand, gravel, and crushed stone. A lightweight material may also be made by whipping air into mixtures containing surface-active agents such as soaps, resins, or detergents, in an amount usually ranging between 0.001 to 0.002 percent by weight of the concrete. For structural concretes the optimum amount of the entrained air ranges usually from 3 to 6 percent of the volume of the concrete. Mixtures of cement and water containing these agents may be used alone or in combination with aggregates. The third method of producing a lightweight concrete is by the introduction of admixtures which react chemically to produce a gas. Powdered metallic aluminum is used most often since it reacts readily with alkalies to produce hydrogen which causes a marked increase in the volume of a cement-water mixture.

Lightweight concretes suitable for use as a load-bearing material usually are made with such lightweight aggregates as expanded clay, shale, slate or blast-furnace slag. These concretes have compressive strengths usually between 1000 and 6000 psi. They weigh one-third to two-thirds as much as dense aggregate concretes and their thermal conductivities are from one-fourth to one-half as much. The use of the air-entraining agents improves the workability and homogeneity of the concrete and increases many fold its resistance to the action of freezing and thawing. Much of the concrete pavement built during the past 10 years was built with aerated concrete.

The use of such lightweight aggregates as perlite and vermiculite in lieu of the heavier aggregates makes possible the production of concretes weighing as little as one-fifth the weight of ordinary concrete and having thermal conductivities less than one-tenth that of dense aggregate concrete.

The development of prestressed concrete resulted from an effort to overcome the basic shortcomings of concrete, *viz.*, low tensile strength, low extensibility, plastic flow under sustained loads and shrinkage due to drying. In pre-

stressed concrete, external forces furnished by the prestressed reinforcement, compress the concrete in those zones where tensile stresses are anticipated; these external forces also overcome the effects of shrinkage and plastic flow by virtue of the prestress in the concrete. Prestressed concrete can thus be regarded as a material quite distinct from ordinary reinforced concrete, since it is an elastic material capable of resisting tension as well as compression. The use of high yield point reinforcement made prestressed concrete possible, since it is now feasible by using high-strength wire as reinforcement to absorb losses of stress due to shrinkage and plastic flow and still leave sufficient prestress in concrete to maintain compression in the concrete under load.

LEATHER

Many of the recent significant developments in the field of materials have been brought about by the necessity of meeting shortages in those common industrial materials that have been known for so long and used for so many purposes that they are commonly taken for granted. Leather—man's oldest industrial product—is no longer available in quantity adequate to supply the multitudinous purposes for which it has been or might be used. Many of these applications are now being served as well or even better by other materials such as rubber, textiles, paper, or plastics, but there are still applications for which leather is in demand in quantities in excess of the available supply. One of these applications is sole leather currently needed for footwear.

Investigations at the National Bureau of Standards are currently being directed toward alleviating this shortage by impregnating the leather with rubber and related polymers so as to increase markedly the durability of the soles and also to permit the use of grades of leather for soles not hitherto suitable for the purpose. Belly leather, which is not normally suitable for soles because of its loose open structure, can be made into a durable sole by impregnation with rubber. Furthermore, with any leather the flesh side is more suitable for impregnation by reason of its fibrous structure. This renders it possible to split leather and use the grain side for shoe linings or luggage and yet to make a sole from the remaining flesh side that will greatly outwear an untreated sole made from the entire thickness of the leather. The penetration of water is reduced to about 50 percent of that of untreated leather; other properties are not greatly altered by the treatment.

Various types of polymers have been used for the treatment of leather with good results including different forms of natural rubber, gutta percha, polybutylmethacrylate, and polyisobutene. The polyisobutene is employed in a 30 to 40 percent solution in gasoline or toluene. The optimum molecular weight is 50,000 to 100,000; polymers of higher molecular weight will not adequately penetrate the leather while with lower molecular weight the wear is reduced.

FIBERS, DETERGENTS AND TREATING AGENTS

Another instance of the conservation and extension of an important natural product is found in the case of pulp for making paper. Hitherto the pulp from coniferous softwood trees such as spruce, fir, and pine has been used to a much greater extent than the pulp from hardwoods such as birch, beech, gum, poplars, and aspen. The increased use of the hardwoods for pulping is important

both because of the growing shortage of softwoods and also because of the economic necessity in forestry operations of utilizing hardwood trees that are not suitable for lumber.

The pulp from hard wood differs from that from coniferous wood in that the fibers are much shorter and have a structure that makes the paper in which they are incorporated weaker, softer, and more absorbent. The increased utilization of hardwood pulp in the production of paper is made possible by bonding the fibers with resin instead of through fibrillation and gelatinization produced by the conventional long beating. In studies of offset papers at the National Bureau of Standards it was found that offset papers made with 75 percent of hardwood pulps compare favorably with papers made in the conventional way with the customary combination of equal parts of hardwood and softwood fibers. The resin bonding was accomplished by the addition of melamine-formaldehyde resin in amounts up to 3 percent. The beating time was one and one-half hours as compared with nine hours in conventional manufacture.

An example of the continued development of fibrous materials is seen in the roofing felt industry where asplund fibers, prepared from wood chips by the defibrator process invented by Arne Asplund of Sweden, are being widely used in the manufacture of roofing felts. These fibers have proven to be a boon to the asphalt-prepared roofing industry, which, though only a little more than half a century old, furnishes approximately ninety percent of all the roofings sold in this country.

Radical development of new materials in construction, building, and electrical industries meets not only some resistance and opposition from people who like things the way they and their forefathers have had them but also building code and labor interests who resist advances which call for a realignment of ideas and procedure.

The new detergents wet, penetrate and emulsify to a remarkable degree. They have low surface and interfacial tensions and a wider range of these properties than ordinary soaps. Many are salts of sulfated alcohols such as lauryl, cetyl or oleyl, or are salts of sulfonated compounds. They are widely used by industry for textile processing, and in insecticides, cosmetics, and lubricating compounds and for cleaning metals and many other materials.

The development of classes of detergents which are equally operable in hard as well as soft water may affect the whole water-softening industry.

There will certainly be many new types of synthetic fibers to join the recent innovations of nylon, orlon, glass fibers, and rayon to displace or improve our material fiber sources. These will be combined with additives to produce desired wetting, water repellent, air penetration, fire resistant, insect repellent and mold or mildew deterrent properties to improve the appearance and usefulness of the fabric.

SILICONES AND INORGANIC COMPOUNDS

Future materials will undoubtedly involve our expansion of inorganic compounds as plastics, adhesives, fuels, and fibrous materials. The development of new organic compounds may not be paralleled in the inorganic field but relatively important studies will be made in this field. As an example of such substances one might consider the silicones. From academic researches on the chemistry of silicon during 40 years, we have new products with unusual

properties called silicones. For example, methylchlorosilanes react with absorbed moisture on surfaces of glass, ceramic materials and textiles to form stable, tenacious water-repellent films. Silicone oils are valuable as lubricants and as hydraulic fluids. They suppress the foaming of petroleum oils. Electrically the silicone oils have very low dielectric losses, and they do not cause rubber to swell. Silicone resins are thermally stable, resistant to oxidation, and good electrical insulators. Silicone rubber popularly called bouncing putty has exceptional thermal stability. It retains its elasticity over the range —55° to 250° C. or higher, is not affected by ozone and has excellent electrical properties.

The non-carbonaceous fuels such as hydrazine (N_2H_4) offer interesting and important possibilities, especially in the rocket propellent field.

The demand for titanium dioxide as a white pigment, now about 200,000 tons a year, is still increasing and its use is effectively relieving the requirements for the scarcer lead pigment in paints. Zirconium dioxide is used as the point material in a new "point" light source which is useful in optical research. Germanium and its derivatives have proven extremely useful in electrical valves as the germanium diode and the germanium triode or transistor. Lithium-aluminum-hydride has opened up a new and important procedure for the reduction of organic compounds and synthesis of new derivatives.

TITANIUM AND METALLURGICAL DEVELOPMENT

Titanium is fourth in abundance among the structural metals, being exceeded only by iron, aluminum, and magnesium. It was long believed to be too brittle to be useful, until its supposed poor qualities were shown to be due to oxygen and nitrogen content. With the development by the Bureau of Mines of a process for producing ductile titanium from its ores, intense interest has arisen in the many possible applications of the pure metal. To a large extent, pure titanium promises to be very useful for many purposes, much work is in progress on the development of titanium-base alloys, some of which might be as superior to titanium for special purposes as stainless steel is to ordinary steel.

The Bureau of Mines has also developed a process for making ductile zirconium. The corrosion resistance of this metal is in general similar to that of titanium, but zirconium lacks the advantage of unusually light weight. Columbium and tantalum, especially the latter, are even more corrosion resistant than titanium and zirconium. Columbium is still mainly used for alloying steel. A recent special use is columbium nitride as an extremely sensitive bolometer receiver surface. The comparative chemical inertness of tantalum has led to its fabrication into acid-proof chemical plant equipment, skull plates, and surgical wire.

Each advance in our machine-age civilization points the way to further advances, provided better metals or materials can be developed to meet the new performance requirements. The development of the automobile, starting about 1900, initiated thinking along strength-weight and reliability lines, and experience gained in the development of the automobile subsequently made possible the airplane. The development of steels which retained their strength at elevated temperatures resulted in improvements in steam-power installations and in the chemical industry where many reactions proceed more effi-

ciently at temperatures higher than were previously attainable. These uses require improved resistance to oxidation and corrosion as well as increased strength and reliability at high temperatures. At present the peak demand for materials for high temperature service is for gas turbines and jet-propulsion engines. At the other end of the temperature scale, there is a demand for better and more reliable metals and alloys for use at very low temperatures encountered in the mass production of liquid air, in airplane operations at high altitudes, and in transportation in the arctic and polar areas. The demand for new and improved metals and alloys is always intensified by war-time activities.

Future developments will produce metals and alloys with higher strengths and better resistance to creep, fatigue, oxidation, and corrosion. Improvements are expected in stainless and alloy steels, in the lightweight metals, aluminum and magnesium and their alloys, in currently available "super alloys" and in protective coatings for high-temperature service and corrosion resistance.

ORGANIC COMPOUNDS

Organic chemicals, the compounds of carbon and hydrogen, oxygen, halogens, or other elements, will without doubt continue to supply our major variety of new synthetic compounds of the future; although the advances in these compounds in the past 125 years have led us now to accept the new and fantastic organic materials of today as commonplace and expected. The founding of the Faraday Society in 1825 almost coincides with the accepted date of the founding of Organic Chemistry as a separate science. (Wohler's synthesis of urea in 1828.) The enormous strides to be made in this field of science in the future will undoubtedly be as significant and spectacular as those of the past century and a quarter; although these advances may be less impressive due to the present highly developed position of the science.

The limitless possibilities in this field are exemplified by the development in recent years of the commercial production of an extremely simple organic compound, ethylene oxide, (CH_2—CH_2, O).

From this one substance are produced ethylene and diethylene glycols and their mono- and diethers, polyethylene glycols, glycol acetates, ethanolamines, and their substitution products. Solvents, plastics, water-soluble waxes, pharmaceuticals, fumigants, and many other products are now made from ethylene oxide and are available in carload lots.

New drugs, foods, dyes, plastics, perfumes, paints, lubricants, refrigerants, and many other substances will continue to flow into the commercial and research markets in the future in increasing amounts.

GENERAL

The recognition of new materials as an important news item in science and industry is apparent in the "New Materials" sections which appear in many of our current technical and trade journals. Among such listings are the "New Materials" section in the *Review of Scientific Instruments,* the "New Chemicals and Specialties" section in the *Chemical and Engineering News,* the "New Products and Materials" section in *Chemical Engineering.*

CONCLUSION

Greater emphasis in the future must be placed on efficient conversion of energy sources, which as Dr. Wiley indicated some 50 years ago would be principally our energy from the sun.

We may expect that the use of radiant energy with the production of carbohydrates may be the principal source of our heating fuels, foods, and combustion engine fuels. For example, it has been calculated that the anaerobic fermentation of the corn stalk material grown within a 10-mile radius of one of our smaller mid-west communities of some 20,000 population would supply the essential heat and power requirements of such a community throughout the year. We may expect that as our supplies of coal and petroleum diminish, greater use will be made of potential water, wind, and tidal power to compensate for the reduced supply of those materials which are largely converted into mechanical energy.

The fantastic fields opened in the application of atomic energy principles may lead to elemental syntheses and energy effects which at the moment are unpredictable by the non-atomic scientist but certainly must be considered in any future material prediction. The use of both atomic and solar energy in the production of useful materials will always be an important problem. It is certainly within the realm of possibility that we may in the future synthetically produce our organic compounds through commercial chemical reactions involving radiant energy and chlorophyll-like catalysts together with simple raw or elemental materials. Foods and drugs will always be a problem of research in the future with a continued production of new substances to increase our span of life, relieve suffering and increase our pleasure.

On the average, material resources should not seriously concern us in the future although minor shortages may cause us to change our mode of living in some aspects. Actually only about 20 percent of the earth's surface has been searched for its resources and vast stores below the surface as well as under the sea have not been tapped to any degree, with the possible exception of oil wells, which have barely encroached beyond the shore line into the vast ocean area.

We can certainly expect that from the trend of new development of materials that just as new or original innovations will continue in the future. The change in availability of the common materials will undoubtedly be the greatest influence in the future developments of new materials. The scarcity of water, iron and many other common materials may result in new methods of conservation recovery and suitable substitutes.

Synthetic materials may be expected to promote and accelerate the production of natural materials. The use of synthetic insecticides, plant hormones, anti-virus compounds and fertilizers and the accelerated and amplified production of natural products together with a program of conservation, utilization of waste and by-products and development of new substitutes should certainly solve the material supply problems of the near and even distant future.

DEVELOPMENT OF THE KINGSBURY THRUST BEARING

ACKNOWLEDGMENT

This article by ALBERT KINGSBURY was published in the December 1950 issue of "Mechanical Engineering," which contained the following introductory statement:

"In 1942, the year before his death, Albert Kingsbury compiled some autobiographical notes entitled "Recollections," copies of which were distributed to members of his family and to a few business associates. By special permission these notes are here published for the first time. Certain personal references and extraneous matters have been omitted. The notes constitute Dr. Kingsbury's own story, in condensed form, of a lifetime spent in lubrication research and the development of the thrust bearing which bears his name."

In June, 1880, I was graduated from the high school in the village (now city) of Cuyahoga Falls, Ohio, in a class of three boys and five girls—the first class formally graduated there—and later I studied for one year at Buchtel College, Akron, Ohio (later, University of Akron), in the Latin-Scientific course.

From 1881 to 1884, I was a machinist's apprentice with the Turner, Vaughn and Taylor Company, of Cuyahoga Falls, and was engaged mostly on rather rough heavy work, such as machines for working clay, wire drawing, etc. The experience there gained was of great value to me later.

In September 1884, I entered The Ohio State University, Columbus, Ohio, as a freshman in the mechanical-engineering course. At the end of the sophomore year, being low in mind and funds, I took a job offered me by Prof. S. W. Robinson, of The Ohio State University, to work on a "wire grip" fastening machine of his invention and design, which was being manufactured by the Carver Cotton Gin Company at East Bridgewater, Mass. My work included drafting, inspection of the work at the Carver company, and trips to various shoe factories around New England to make repairs or alterations in the wire-grip machines already in use. After less than a year at this work, I became discouraged by certain features of the situation beyond my control and returned to Ohio. There I secured work with the Warner and Swasey Company, in Cleveland, as machinist, working mostly on 16-in. engine lathes and making parts for their regular line of machine tools, such as small turret lathes. At that time they were building the mounting for the famous Lick telescope (36-in. object lens) and it was my privilege to work on some parts of the mounting.

EARLY WORK IN LUBRICATION AT CORNELL

In the fall of 1887 I entered Sibley College, Cornell University, in the junior class in mechanical engineering, and continued there until graduation in 1889. In the latter part of the junior year arose the first of my experiences that definitely turned my thoughts toward the subject of lubrication, which has been the principal item in my lifework. The head of Sibley, Dr. R. H. Thurston, assigned to me the laboratory problem of testing the bearing metals submitted by the Pennsylvania Railroad Company. There were some five samples, in the form of half-bushings about 2 in. × 2½ in., arranged for tests in a small Thurston oil tester. These samples had already been tested for wear in the laboratory at Sibley by students or others who had reported that some of the samples were much worse than others. I received no specific instructions for the tests, and so I naturally started by refitting all the samples carefully to the test journal by scraping. Then the samples were successively tested in the small Thurston machine, with varying loads, speeds, and oils, with the result that all the samples showed exactly identical results—*no wear* at all, though weighed in a delicate balance before and after test. I reported these facts to Dr. Thurston, who then suggested using kerosene, ordinarily not a lubricant. Thereafter certain tests showed a smaller coefficient of friction (0.0005) than had ever previously been found in any published report of bearing tests. Again Dr. Thurston offered no explanation. All this left me with a desire to find out something about the operation of oils in a bearing, since such tests could not explain the apparent mystery. The fact that the needed explanation had been published in 1886 by Osborne Reynolds in the Philosophical Transactions was not known to us at Sibley College at that time, though it was known to my former classmate, F. L. O. Wadsworth, at The Ohio State University, who about 1888 wrote an abstract of Reynolds' paper.

I pursued the studies at Sibley College from 1887 to 1889. About commencement time (1889) Dr. Thurston recommended me for a teaching job in the New Hampshire College of Agriculture and the Mechanic Arts at Hanover, N. H. The dean, Professor Pettee, invited me to come up and be seen, but I only sent a photograph, promising to be on hand for the fall term. The compensation offered ($100 monthly) seemed huge to me after the years of study and work I had put in to pay the expenses of college life.

I had the teaching of the courses in mechanical enginering and physics with the assistance of John Brown as instructor in the machine shop, an excellent mechanic of the Old New England type and an amiable man. There were also several instructors in woodworking; of these I remember best Allen G. Lowell and, later, George H. Furbish, as being very skillful.

There were, I think, 18 students in all during the year 1889-1890. At the close of the college year I resigned, having been offered a job by my highly esteemed cousin, Horace B. Camp, again at Cuyahoga Falls, Ohio, a very helpful man, much older than myself, of common-school education but of much experience in life. He had invented a brickmaking machine (among many previous inventions) and was bent on putting up a machine shop to manufacture it. He fancied that my good education should prove to be a great help to him in this matter. We erected a brick shop, 40 × 100 ft., equipped it with tools, and began business, I being the superintendent. However, after a few months, business did not develop as anticipated, and as Professor Pettee had always urged me to return to New

Hampshire College, Horace finally advised me to accept the offer (a full professorship in mechanical engineering with a salary of $2000 per year). So I returned to Hanover for the fall term, 1891, and retained the post of professor of mechanical engineering until July, 1899.

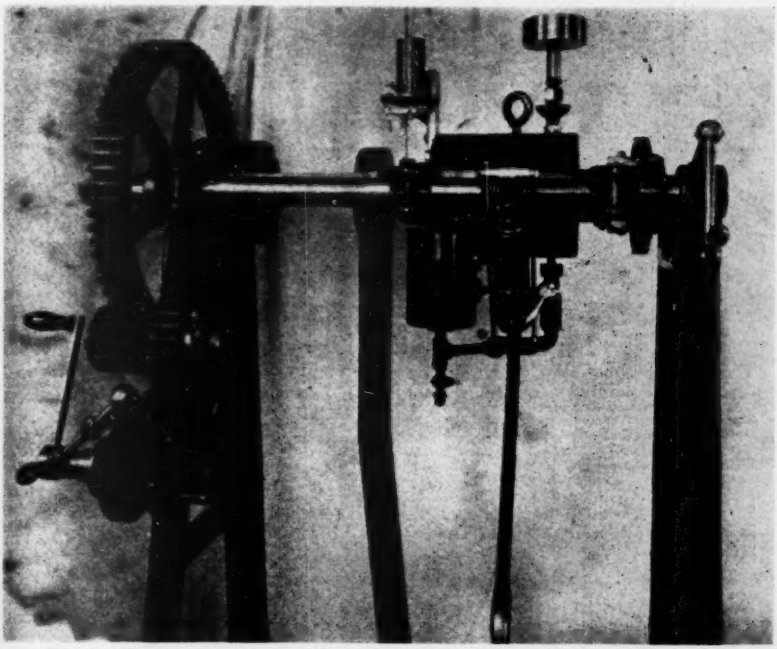

FIG. 1.—Torsion-Compression Machine built by Albert Kingsbury about 1892

[This machine was built to study friction in screw threads, particularly threads used in an action similar to that of a *jack screw*. The power head at the left was designed to furnish the twisting power or action to a sample placed between the power head and the weighing head at the top of the pendulum. The pendulum is the slightly bent member shown between the pump handle and the gear mechanism. The pendulum, the lower end of which is not shown, was bent back so that its center of gravity would be directly below the center of the support sleeve of the support (ball) bearing, thus eliminating any binding. A brass finger, just visible above the round bar connecting the two side frames, indicated the relative motion between the two heads. The modified steam-engine indicator is specially equipped with a stem which moves vertically as the center of gravity of the pendulum moves horizontally, and hence this movement is proportional to the torque applied to the sample. The cylinder to which the pump is attached contains a piston which, when under pressure, furnishes a thrust on the spindle which carries the pendulum. The pressure on the piston is measured by the pressure-gauge testing unit mounted on the top of the cylinder at the right. The crank at the right was for the purpose of moving the whole weighing head in order to accommodate different lengths of sample. Thus this machine could subject a sample to a combination of twisting and compression and could weigh each of these actions independently.]

TEACHING AND RESEARCH

During the years 1891-1892, we of the faculty, especially Professor Pettee and I, were much concerned with the building of the new buildings for the College, at Durham, across the state from Hanover. We moved to the new location in 1893. While I was at Hanover, and at all times, my having charge of the shops gave me opportunity to continue my research in the questions

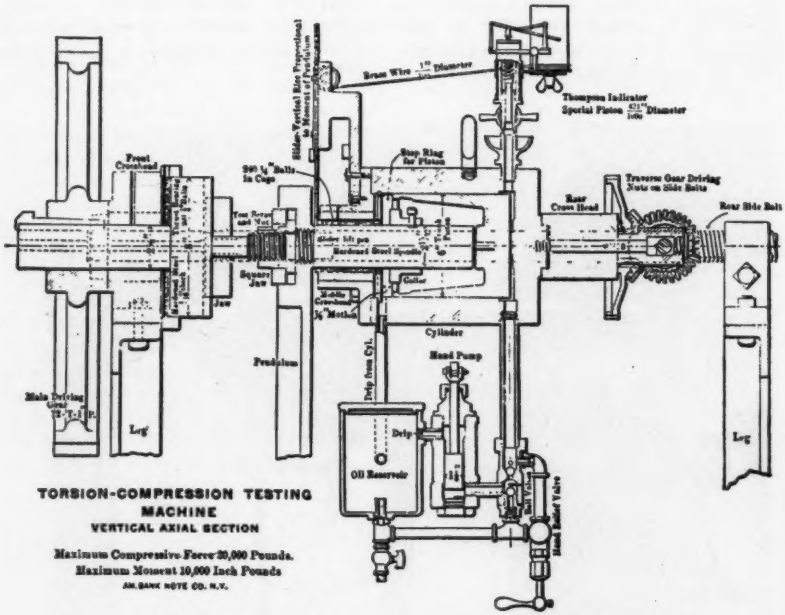

FIG. 2.—Sectional drawing of Torsion-Compression machine shown in Fig. 1 (Reproduced from Transactions ASME, vol. 17, 1896, p. 98)

about lubrication that arose in my junior year at Cornell, and I made a number of investigations, generally with a view to using the results as a means for instruction of the students. I rarely kept any record of these investigations.

First I built (mainly with the help of John Brown) a "torsion-compression" testing machine (Figs. 1 and 2). On this I made a long series of tests upon the friction of screws and nuts. These tests were the basis of a paper[1] I presented at the meeting of The American Society of Mechanical Engineers in New York, December, 1896.

The compression element of this machine, a piston 6 in. diameter and 6¼ in. long, fitted without packing of any kind to a heavy cylinder on which I had long meditated with doubt and mental questioning, proved to be not only entirely suited to the purpose but also a very interesting bit of mechanism in itself. I found that if piston and cylinder were taken alone, the axis being vertical, the piston could be spun rapidly, apparently without contact with the cylinder wall. Then John Brown found that the same action occurred even with the axis *horizontal,* and he called my attention to this. This was surprising, because the piston weighed 22 lb., being hollow and of trunk-piston type. I shortly came to the conclusion that this must be a case of lubrication, the *air* acting as the lubricant. After playing thus with these parts for some time, we

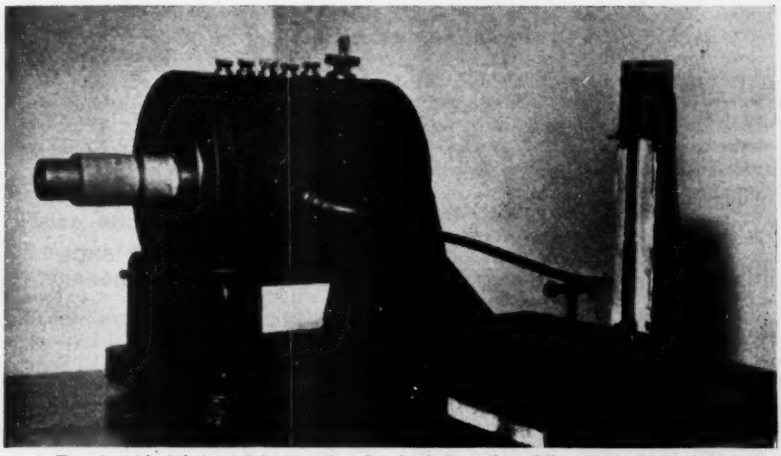

FIG. 3.—Air-lubricated journal bearing built by Albert Kingsbury about 1892

[Six-inch-diameter cast-iron rotor has a wooden handgrip. A screw-driver slot is provided in end of shaft so that a screw driver in a hand or breast drill can be used to get high-speed rotation. The large knurled screw plug with wooden insert plug is used to vent the air space at the back of the cylinder. This allows insertion of the rotor and, when vent is closed, prevents withdrawal of the rotor. The smaller knurled screw plugs (five in number) are for insertion of micrometer measuring instruments so that clearance between the rotor and stator, i.e., thickness of the air film, can be measured accurately. The stator can be turned in the wooden support so that the micrometers can be oriented at any desired angle, thereby permitting measurement of air-film thickness at any position. This piece of apparatus is in regular use at Worcester Polytechnic Institute in classes in machine design and in lubrication studies.]

made a new cylinder (Fig. 3) and a solid piston weighing about 50 lb., together with bits of apparatus to show the air pressure at various places in the air film in the space between piston and cylinder wall (mean space 0.0016 in.), and the variations in this space with the speed of rotation of the piston. This apparatus was exhibited before the Association of Agricultural Colleges at their meeting in Washington, November, 1896, and attracted much interest on the part of engineering teachers.

I then was invited to exhibit it before the engineers at the Bureau of Steam Engineering at the Navy Department, which I did. Among the listeners there was John H. MacAlpine (later well known because of his association with Admiral Melville in the promotion of the reduction gear). After my talk he went out and shortly reappeared with a big book in which he showed me that "Reynolds says this, while you said so-and-so." In fact I *had* made an inaccurate statement in my brief notes. But this was my first sight of that remarkable paper by Osborne Reynolds[2] which explained for the first time in print most of the phenomena of lubrication that were shown in Tower's experiments[3] and also my puzzle of 1888 at Cornell.

On returning to Durham, I got the loan of the Philosophical Transactions from the Boston library, studied Osborne Reynolds' paper at length, and repeated my experiments with the air-lubricated bearing more fully in the light of Reynolds' theoretical work.

From this there resulted my paper[4] published in the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.

PIVOTED-BLOCK THRUST BEARING

In reading the section of Reynolds' paper dealing with flat surfaces, it occurred to me that here was a possible solution of the troublesome problem of thrust bearings. Reynolds showed that if an extensive flat surface rubbed over a flat surface slightly inclined thereto, oil being present, there would be a pressure between the surfaces distributed about as sketched in Fig. 4. The maximum pressure would occur somewhat beyond the center of the bearing block in the direction of motion, and the resultant would be between that maximum and the center line of the block. It occurred to me that if the block were supported from below on a pivot, at about the theoretical center of pressure, the oil pressures would automatically take the theoretical form, with a resulting small bearing friction and absence of wear of the metal parts, and that in this way a thrust bearing could be made, with several such blocks set around in a circle and with proper arrangements for lubrication.

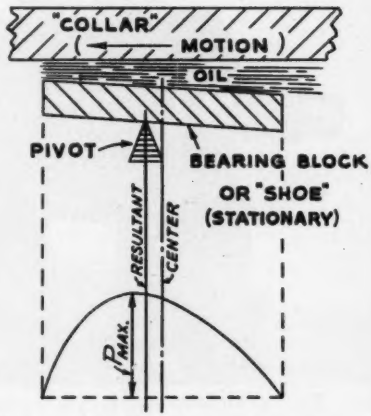

FIG. 4.—Albert Kingsbury's sketch of pressure distribution in offset shoe

I kept this idea in mind for a long time, but hesitated to make trial of it because the unit pressures that might be required, say, for the first long vertical shafts (1891) at Niagara Falls, where the pressure was 400-500 psi, were far beyond those familiar in existing thrust bearings that worked satisfactorily (for example, 40 to 50 psi in the bearings for ships' propeller shafts). Also, the requirement of the lopsided form of the bearing, apparently permitting rotation in one direction only, was a sticker. However, I decided to *try*, and in 1898 Mr. Brown and I built a bearing with the blocks supported *at the center line* of the blocks, and not on frictionless pivots, but on small spherical bosses projecting from the blocks. In 1898 I made tests of this bearing in the torsion-compression machine previously used for tests for friction of screws, with certain homemade roller devices to carry temporarily the reverse thrust of the bearing, and with a strip of sheet brass bent to catch the oil which was supplied in a small stream through the center of the bearing, as it was thrown from the rotating part.

The tests were entirely successful. The bearing loads, which were small at first, were gradually increased, finally reaching 4000 psi or more, the speed being about 285 rpm.

In 1919 I gave expression to my appreciation of Reynolds by a contribution to the University of Manchester to form at least the initial basis for an "Osborne Reynolds Fellowship." The first incumbent of this fellowship was Reynolds' son, F. D. Reynolds, who was working on the problems of the screw propeller.

It was my practice to give all reasonable teaching assistance to my students in thesis work, and for this purpose I utilized whatever research material I happened to have in hand at the time, the students paying the costs of small

incidental materials. In the class to be graduated in 1898, were Moore and Morgan, who were building a small belt-driven electric generator (I furnished the ideas for the self-lubricating bearings). Colby and Kenney of the class of 1899 made tests with varying clearance on a small steam engine (using parts arranged by me and a hydraulic dynamometer of my design and construction). Clement worked alone on a design on a small vertical steam engine; Baker and Putney on tests of the thrust bearing that I had previously tested (1898).

In July, 1899, I left my post at New Hampshire College for one at the Worcester Polytechnic Institute where I was appointed professor of applied mechanics and had charge also of the laboratory where material tests were made. I gave lectures and other instruction, but also spent much time in the laboratory, in classwork, and in my personal research in lubrication especially. There were two tension-testing machines and a large torsion machine (at Worcester Polytechnic Institute), but nothing else.

I shortly made a deal with Dr. Murkland, president of New Hampshire College, whereby my old torsion-compression testing machine and all the test-pieces used in it, and some other pieces, including the thrust bearing were transferred to Worcester. At Worcester, I also had constructed a small machine for journal friction tests, Fig. 5, which proved to be quite interesting and instructive to me as well as the students.

Among the students preparing theses for graduating in 1900 were Graffam and Traill, who made, at my suggestion, a new base or support for the shoes of the thrust bearing, with long radial supports of cylindrical form for the shoes. These students made very successful tests of the new bearing.

In these tests, as well as in those of Baker and Putney at New Hampshire,

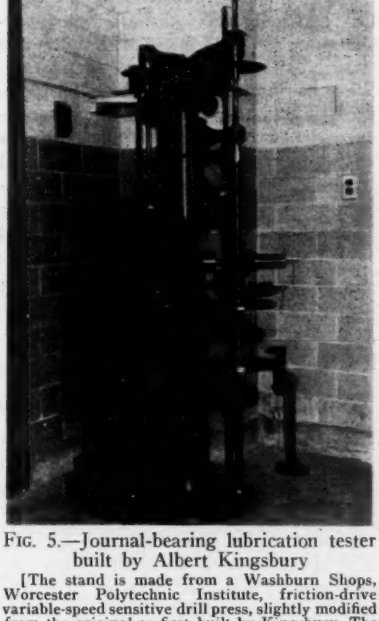

FIG. 5.—Journal-bearing lubrication tester built by Albert Kingsbury

[The stand is made from a Washburn Shops, Worcester Polytechnic Institute, friction-drive variable-speed sensitive drill press, slightly modified from the original as first built by Kingsbury. The spindle and weighing device are just as originally designed, however. The cup which contains the bearing shoes and the lubricant is shown above the circular table. The hand screw on one side of the cup varies the pressure on the bearing and the pressure is indicated by an indicator on the barrel. The counter weight opposite the pressure screw balances the unit so that it hangs freely. The bearing unit extends nearly to the base of the stand, by means of a hollow tube, and the support is by means of a wire or torsional spring which comes back up to the bracket just under the bearing cup. The bearing rotor is at the base of the spindle to which it is connected through two universal joints. Lubrication characteristics for various lubricants under varying pressures and temperatures were investigated in this machine. The machine is used as regular laboratory equipment at W.P.I. and has been so used for many years.]

the good operation with "central supports" for the shoes was not explained by the theory of Reynolds, who assumed constant viscosity in the oil. It was explained in later years by H. T. Newbigin, then manager of the Mitchell plant, who suggested that, because of the continuous friction heating, the oil became less viscous as it passed in the film from the leading edge to the trailing edge of each shoe; and this appears

to be the main explanation. The idea of "central supports" was afterward patented in England by Cooke, who was associated with the Hon. Charles A. Parsons in the steam-turbine business. It was probably not known or recognized by anyone that I had used the idea in my very first bearing in the United States, and of course I offered no objection to the British patent as I did not hear of it until the patent was issued and it did not affect my work.

I later used this idea extensively, and still use it, in my American practice.

The Graffam and Traill construction introduced a new difficulty which arose from the lack of radial tipping of the shoes, so that, because of bending of the support, much scraping was required to make the shoes fit the rotating disk. Graffam later wrote me a suggestion which probably, if used, would go a long way toward meeting the difficulty, but it was never tried, as other and better ways were used by me originally and later. The same suggested improvement was also proposed to me by Putney in 1909.

TEACHING ABANDONED FOR ENGINEERING WORK AT WESTINGHOUSE

In June, 1903, through the good offices of B. G. Lamme, my old friend and classmate at The Ohio State University, who was shortly to be chief engineer of the Westinghouse Electric and Manufacturing Company, I got employment at the East Pittsburgh works as a "general engineer," working mostly on mechanical matters because I was not very well versed in electrical matters. Notwithstanding this, when a call came from the Canadian Westinghouse Company for an electrical engineer, I was sent to make a report to the Canadian Pacific Railway on the electrical equipment installed by the General Electric Company at various places on their system. I protested that I was not an electrical engineer, both to the Westinghouse people and to Sir Thomas Shaughnessey, then president of the Canadian Pacific Railway. I spent two or three months in the summer of 1904 on this work at Montreal, Winnipeg, and Port Arthur, with results that apparently satisfied all concerned. Also, I learned much about electric motors from the tests I found necessary.

When I returned to East Pittsburgh I was given work on the mechanical design of the rotors for turbine-driven generators which involved high rotative speed and, therefore, high mechanical stresses. I continued with the Westinghouse Electric Company until 1914, being a consulting engineer for them and for the Westinghouse Machine Company (near by) during later years. About this time I set up as consulting engineer on my own account, with an office in the Oliver Building, Pittsburgh.

ATTEMPTS TO DEVELOP THE THRUST BEARING COMMERCIALLY

During my work at East Pittsburgh I missed no chance of promoting my old idea of the thrust bearing with these two companies. In 1904 the Electric Company had to build a large electric motor with a vertical shaft, and for this motor they made, at my suggestion, a thrust bearing of my type. This was installed in the motor for "shop test." The test run was made at night, without my knowledge and attention, and the bearing was reported to have "run hot" and was, therefore, discarded. I never saw it again. It was replaced by a ball

bearing, as originally intended. I could realize from later experience why my bearing "ran hot" in this case. Firstly, it was much too large for the job, being designed for a load of only 50 psi (400 would have been better), and secondly, the speed was quite high, 750 rpm. Probably the oil was unsuitable also, perhaps too viscous for this case. But the drawing of this 1904 bearing being the only one then available, was used with my application (1907) for a United States patent.

In 1909 the Electric Company built a large vertical motor for the Minidoka irrigation project in Idaho. This motor was provided with a ball-bearing thrust. The company had sent an engineer to look over the plant and the products of the bearing maker in Philadelphia and he had reported favorably on the plant and products, but when the motor was subjected to shop test for a day or two, I found that the ball bearing already showed indications of incipient failure. I, of course, reported this to H. P. Davis, vice-president and manager of engineering, asking that one of my designs be tried instead. He would not consent to this trial except at my personal expense for the parts required. Accordingly, the works made, at my cost, a bearing to replace the ball bearing, working from my free-hand sketches and notes which, I remember, were very crude indeed. This was ready and tested under my supervision in about a week and it operated perfectly. But the attitude of the company officials who viewed the operation seemed to be "there ain't no such animal," and the bearing was therefore rejected and the motor was finally equipped with a roller bearing before being shipped to Idaho.

Some 14 years later the U. S. Army Engineers at the plant in Idaho applied to me for a bearing for this motor to replace the roller bearing, and this I furnished them. I suppose I have heard the last of that particular job. My bearings appear to last indefinitely long in service, since those installed 30 years ago are still operating well.

About 1906 I told Mr. Davis that if the Electric Company would obtain a patent and would develop the bearing to the point where they could determine its value, they could then own the patent by paying me what they thought proper for it. Hence Mr. Davis had the Legal Department start an application through R. J. Dearborn, of that department, who had been one of my students at Worcester Polytechnic Institute.

Before long this matter came to the attention of the president, then E. M. Herr, who did not approve it; so I had to bear further expense myself. The patent application was filed in 1907. The first action of the Patent Office was a denial, because of Mitchell's patent on the same idea in England, issued in 1904. Thereupon, Dearborn filed for me affidavits of Baker and of Putney, and later those of Graffam and of Traill, which established my precedence of a few years in the matter. As a result, the Patent Office granted me a patent, No. 947242, issued in 1910.[5]

During 1910-1911 the Westinghouse Machine Company became interested in the thrust bearing, through H. T. Herr, vice-president, and Francis Hodgkinson, chief engineer. Before taking the license I proposed, they made, in their works, extensive tests of the bearing applied to a high-speed steam turbine (3600 rpm). The bearing worked very well and the bearing area was reduced in successive tests until the babbitt-metal facing was crushed by the pressure (7000 to 8000 psi). This surprising result convinced them, so they took the license (my *first one*) and continued to work under it through the life of the patent.

A few years later, the Westinghouse Electric Company also took a license for their own work, and in later years other manufacturers took licenses. These

later licenses contained a restriction as to size (100 sq. in., or less, of shoe area) because it had seemed to me for a long time that relatively moderate sizes were easy to make and install, since the only difficulties I had met occurred with the larger bearings (48 to 61-in. sizes) and I preferred to keep the large sizes for my own manufacture and installation.

IN BUSINESS FOR MYSELF

Early in 1912 the Pennsylvania Water and Power Company gave me a chance to apply a bearing in their hydroelectric plant at McCall's Ferry (now called Holtwood) on the Susquehanna River, where they had had much trouble with the original roller bearing supplied by a Philadelphia concern. The load to be carried was about 200 or 250 tons and the speed, 94 rpm. I made a drawing of the bearing and showed it to H. T. Herr, asking if the Machine Company could build it for me. This they consented to do under my direction, on being assured that I could pay for it. This happened just at the time when a $5000 twenty-year "endowment" insurance policy, that I had assumed in 1892, matured. I have always advised young men to follow my example, because this matured policy gave me a really firm start in business, and I did not have to borrow money.

I signed a contract with the Pennsylvania Water and Power Company (a very stiff one, from my point of view) and got the bearing made and installed. On the first trial run the bearing failed at once and completely by the "wiping" of the babbitt metal of the shoes; the cast-iron disk or "runner" was merely scraped, not polished. I explained to the company what I thought to be the reason for the failure and had the parts shipped back to East Pittsburgh. After properly polishing the runner and pouring new babbitt metal on the shoes, the bearing was replaced in the 10,000-hp unit at Holtwood. After several days and nights of work at refitting the babbitt surfaces, further trial runs were made, with complete success, and the unit was put in service again.

I had worked day and night with the gang on the job and was not without discouragement. On one of the last nights, as I emerged from the powerhouse at 2 or 3 o'clock in the morning, intending to go to bed at the boarding-house about 400 ft. up the hill, all my sentimentality was awakened by the sight of the great planet Jupiter, hanging like a huge torch above the dark valley. No sound could be heard except that of the rushing river. This experience gave me renewed inspiration, and I shall never forget the scene.

The continued good operation of this bearing at Holtwood (which was followed there by nine more bearings in additional units in later years) was the reason, 25 years later, for a celebration of its installation in 1912. At a dinner held at Holtwood in July, 1937, attended by Mrs. Kingsbury and myself and most of the officers and employees of the company, much was said in praise of the bearing, which really seems to have been the financial salvation of the company. (The original roller bearings, which cost about $5000 each, required a vast amount of very expensive servicing and repairs, with expensive shutdowns). After the dinner we saw, in the power plant, the parts of my original bearing, removed for inspection, and made actual measurements of the amount of wear on the blocks (or shoes)—at most 0.005 or 0.006 in. near the trailing end. The plant engineers calculated from this a "probable life of 1300 to 1700 years" for the bearing.

After the success at Holtwood in 1912, there were frequent demands for the bearing for hydroelectric generators, at Keokuk on the Mississippi, Cedar Rapids on the St. Lawrence, and elsewhere. I had working arrangements with the Westinghouse Machine Company and the Canadian Westinghouse Company to build bearings for me, as required. Up to 1918 this work was done largely for the U. S. Navy.

In 1921 the Machine Company found that they could no longer keep up my work. I had at the time a small shop in Philadelphia (on Cherry St.), but soon bought an old plant on Tackawanna St., Frankford, in the northeast part of the city, and new and second-hand machine tools for equipment, and began to manufacture bearings there. Soon more space was required and was built there, and I am now (August, 1942) again building additional space to accommodate the great amount of work under way for the U. S. Navy in the present World War.

The U. S. Navy began to use my bearing on propeller shafts in 1917, although I had much earlier tried to get the Bureau of Steam Engineering interested. I have been told (by someone I cannot now identify) that it was the fact that the British Government was using the Mitchell bearing that caused the U. S. Navy to adopt my bearing. Even then the head of the Bureau, Admiral Griffin, who apparently assumed that I was an interloper, asked Admiral Dyson to check up on this matter. Dyson reported to him, and also to me, that I had a perfectly good U. S. patent. After that the contractors for Navy ships used the bearings in large numbers, so that it took some 10 to 12 machine shops, in addition to the Westinghouse plant, to supply the demand during the remaining years of the First World War.

However, we met the demands with no delays and we are now again continuing to do so in the present World War, for our plant in Philadelphia is loaded to the limit, and about eight outside plants are helping us.

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2. "On the Theory of Lubrication," by Osborne Reynolds, Philosophical Transactions, 1886.
3. First Report of the Research Committee on Friction: On Friction, Experiments (Friction of Lubricated Bearings, B. Tower, Proceedings of The Institution of Mechanical Engineers, 1883, p. 632 and 1884, p. 29).
4. "Experiments With an Air-Lubricated Bearing," by Albert Kingsbury, JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, vol. 9, 1897.
5. In a paper presented at a meeting of the ASME Metropolitan Section in New York on May 17, 1929, "Progress of Fluid-Film Lubrication" (Trans. ASME, vol. 51, 1929, paper MSP-51-21) A. G. M. Mitchell said: "In this connection the author avails himself of the opportunity to explain that the pivoted thrust bearings known in America and Europe respectively as the 'Kingsbury' and 'Mitchell' bearings are in principle the same, and to state that the development of these bearings was effected in its early stages by Professor Kingsbury and himself independently in their respective countries without knowledge of each other's work. Professor Kingsbury's work was commenced a few years earlier, though his first publication on the subject was later than the author's."—EDITOR.

RADIAL VERSUS AXIAL COMPRESSORS

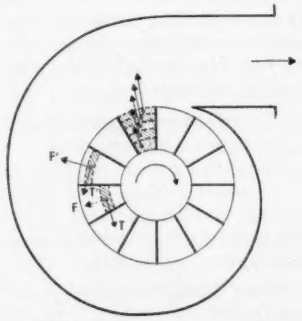
ACKNOWLEDGMENT

This article, written by DR. W. TRAUPEL, was published in "Sulzer Technical Review," No. 2, 1950, under the title "Sulzer Turbo-Compressors." It describes the method of operation and the main features of radial and axial compressors, and discusses the advantages and disadvantages of each.

When over ten years ago new avenues were opened up in the construction of internal combustion engines — highly supercharged Diesel engines, Diesel gas producers and finally the gas turbine proper—it soon became clear that these new developments could only be a success if it proved possible to build turbo-compressors of high aerodynamic efficiency.

As the special qualities of the various types of turbo-compressor are in fact of great significance for many industrial applications, a detailed review of the characteristic features of these machines should be of real value to all compressor users. These features, however, depend essentially on the method of operation of the compressors, so that an understanding of their behavior in service can only be based on a clear grasp of the principles they embody.

Radial compressors—The most obvious method of compressing any liquid or gaseous medium by purely dynamic means—without the use, that is, of pistons or other displacement bodies—is the application of centrifugal force.



F, F' Centrifugal forces
T, T' Reaction forces acting on the runner blades

Fig. 13. Diagram illustrating the method of operation of a radial compressor runner.

Centrifugal machines consequently held a leading position for many years in compressor construction, as for that matter in pump construction also, and it was only in a later phase of development that other types of machines were gradually introduced.

Fig. 13 illustrates the working principle of a machine employing centrifugal force. In the simplest case the

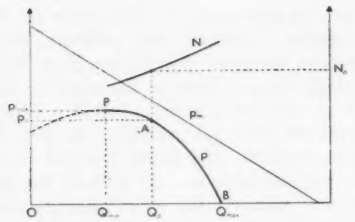
impeller is fitted with radial blades. The fluid medium situated between these blades is flung outwards by centrifugal force as the wheel rotates. The figure illustrates how this process affects a given unit quantity of gas. On the left the positions of this unit of gas are shown at two consecutive moments. In the lower position, the centrifugal force F is acting on the gas. A moment later the unit has moved a short distance outwards and is now subjected to a centrifugal force F', which is greater than F. It is important to note in what way the impeller does work on the gas. The further the gas moves outwards, the greater will be its peripheral velocity. It is thus continually accelerated as it moves towards the periphery of the impeller, and in order to impart this acceleration the blade must exert a peripheral force on the gas. Consequently the blade itself is subjected to an equal reaction force, which is indicated in the two positions of the gas unit by arrows T and T'. It is these tangential reaction forces, acting opposite to the direction of rotation, which the prime mover has to overcome. The faster the outward movement of the gas, the greater is the tangential acceleration, and with it the tangential reaction forces and thus the power requirements of the machine.

The individual centrifugal forces acting on each unit quantity of gas in the space between any two blades all add together, as Fig. 13 shows, to exert a force on the gas lying outside of the impeller and already flowing off to the point of consumption, with the result that this gas is put under pressure.

If we now assume that the discharge pressure of the machine is reduced, for instance by the escape of some of the compressed gas from the delivery pipe to the atmosphere, the gas in the impeller will then obviously flow more rapidly into the delivery pipe, and the total flow of gas through the machine will therefore be increased. At the center of the impeller, however, the pressure must always be lower than in the space from which the gas flows to the machine, for it is only on account of this pressure gradient that gas continues to flow to the impeller. The faster the gas flows to the impeller, i.e., the greater the delivery quantity, the lower this pressure at the impeller center will be. In the last resort it may sink so low that the centrifugal force of the impeller is only just sufficient to bring the gas back to its original pressure. The machine then supplies a very large quantity of gas but no longer generates any pressure, acting purely as a delivery machine. If on the other hand the pressure behind the machine builds up, the delivery quantity is reduced accordingly. Finally the delivery branch of the machine might be completely closed, and in theory at least the impeller would then generate the highest pressure of which it is capable at the given speed.

The working principle of such a machine at once reveals that its delivery pressure and quantity are functionally interconnected, a high pressure corresponding to a low delivery quantity and vice versa, so that the pressure is reduced to nil when the quantity reaches its maximum.

A more accurate analysis of the process shows that this interconnection is in theory a linear function as represented in Fig. 14 by the straight line ρ_{th}. Owing to the inevitable losses, however, the real pressure ρ is always lower than the theoretical pressure, the difference increasing as the delivery quantity moves away from the value Q_0 for which the machine is designed, since the shapes of the individual members are then less well suited to the modified flow conditions. The characteristic representing the actual behavior of the machine finally becomes a curve ρ which approaches nearest to the theoretical straight line ρ_{th} at the normal service



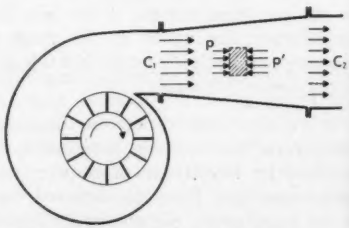
p_{th} Theoretical pressure curve as a function of delivery quantity (theoretical pressure characteristic)
p Actual pressure characteristic
N Input curve
Q Delivery quantity
A Normal service point
B Service point with no pressure and maximum delivery
P Surging limit

Fig. 14. Characteristic of the radial compressor.

point A, and reaches the zero value at B. Here the whole of the pressure generated by the impeller is converted into velocity or is consumed by the internal frictional and eddy losses. The internal losses also increase rapidly in the range of very low delivery quantities, so that from a certain point P onwards a further reduction of the quantity will even lead to a reduction instead of an increase in pressure. In this region no further stable operation is possible because the machine begins to pulsate or "surge," a condition which may lead to serious trouble and must therefore be avoided at all costs. P is known as the "surging limit" of the working range.

As explained above, the input of a centrifugal impeller is greater, the faster the gas moves outwards between its blades, i.e., the greater the delivery quantity. The input curve N (Fig. 14) will therefore rise with increasing delivery quantity and will reach its maximum when the pressure has sunk to nil. These two features, the increase in the delivery quantity with decreasing pressure and the simultaneous increase in the input, are characteristic of the radial compressor, as also of the centrifugal pump. The behavior of the radial compressor is thus diametrically opposed, for instance, to that of the piston-type compressor, a point which must be taken into account in the planning of new installations.

Fig. 13 shows diagrammatically the simplest possible form of radial compressor. In practice these machines incorporate numerous refinements of design which have resulted from the study of the aerodynamic problems involved. It will be noted above all that the air leaves the impeller at a high tangential velocity, and that this kinetic energy would be of no practical use if it were not for the most part converted into pressure by the provision of a diffuser. The simplest type of diffuser consists of a conically expanding pipe (Fig. 15). If a flowing medium fills the whole cross-section of a widening conduit of this kind, so that there are no zones in which it stagnates or even turns back on its course, the outlet velocity C_2 must obviously be lower, owing to the larger cross-section of flow at this point, than the inlet velocity C_1. If a unit volume of gas is followed in its passage through the tapered conduit, it will be found to slow down, which is only possible if there is some force acting upon it in the direction opposite to that of its movement. As the friction of the walls is far too slight to account for this retardation, it can only have one cause the pressure p acting on the front



C_1, C_2 Velocities of medium entering and leaving the diffuser
p, p Pressures acting on the bounding surfaces of a unit quantity of the delivery medium

Fig. 15. Diagram illustrating the effect of a diffuser.

of the gas is greater than the pressure p acting behind it. The pressure therefore rises continuously along the conduit, i.e., part of the kinetic energy of the gas is converted into pressure energy.

In practice diffusers do not normally take the simplified form shown in Fig. 15. A commoner execution is illustrated in Fig. 16. The impeller is surrounded by a circle of stationary blades enclosing channels which widen in the direction of flow, so that the effect is the same as in the tapered conduit. This effect is only obtained, however, when the flowing medium uniformly fills the whole of the cross-section of the channel, i.e., when it follows the bounding surfaces without any pockets or dead spaces being formed. To attain this end is often a difficult matter, and this is in fact one of the points on which the work of the investigator and the art of the designer have to be concentrated.

Fig. 16. Radial runner with backward curved blades and diffuser wheel surrounding it.

The impeller shown diagrammatically in Fig. 16 has blades which are not arranged radially but are curved backwards, a form which is much used for multi-stage compressors.

The pressure which can be generated in a single impeller is limited by the maximum peripheral velocity admissible for mechanical purposes, which today

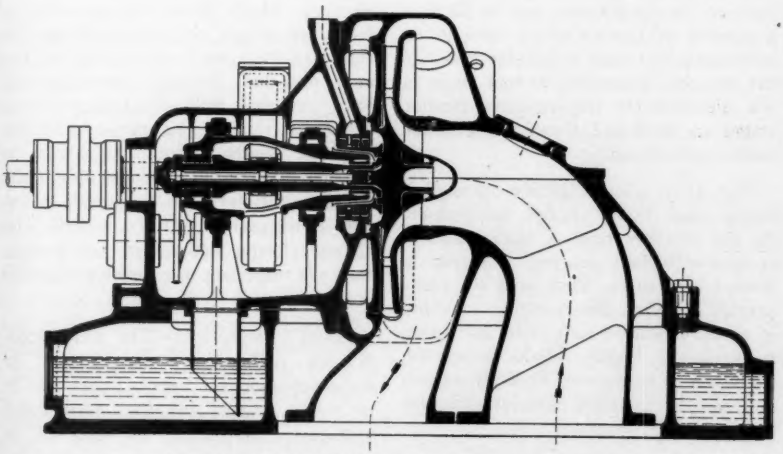


Fig. 17. Cross-section through a single-stage Sulzer monobloc radial compressor.

The runner is driven through gearing which is combined with the compressor to form a single unit.

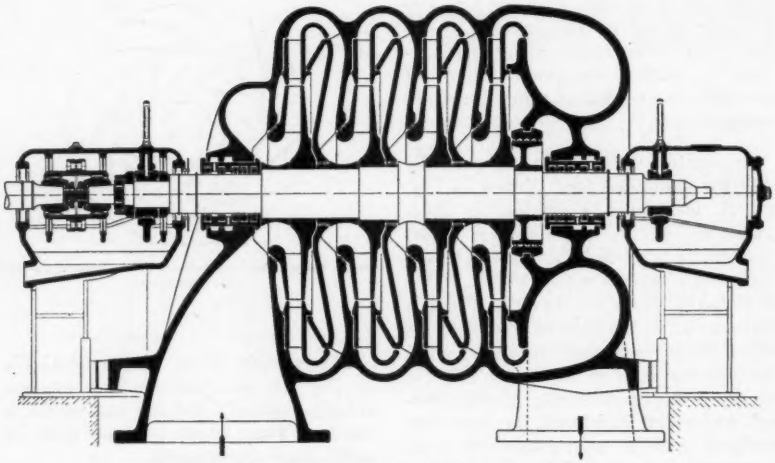


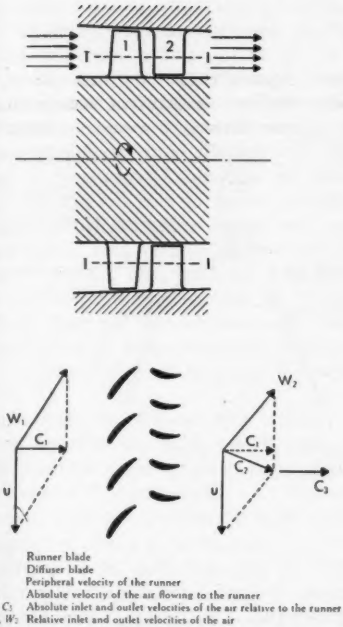
Fig. 20. Cross-section through a four-stage Sulzer radial compressor.

lies at about 1000 ft. per sec. for industrial compressors with special impeller forms. It also depends on the nature of the gas, its temperature and so forth—a number of factors which have to be investigated in each particular case. If the pressure generated in one stage is not sufficient for requirements, further stages are employed, thus leading to the multi-stage design.

Fig. 17 is a cross-section through a single-stage Sulzer radial compressor. As the impeller runs at high speed, it is driven through gearing. The gear is housed in a single block with the compressor, so that the resulting machine is a self-contained unit with low space requirements. Highly reliable in service, the machine needs very little attendance and can be installed without difficulty wherever it is required.

The internal design of a four-stage Sulzer radial compressor is shown in Fig. 20. The form of the impeller blades and of the stationary diffuser blades surrounding the impellers is essentially the same as in the diagram of Fig. 16. In Fig. 20, however, attention should be paid to the peculiar form of the channels which divert the gas coming from one stage and return it to the center of the rotor to be supplied to the next impeller. Accurate investigations have revealed that the energy losses occurring during the passage of the working medium from one stage to another may be very considerable if the aerodynamic form of the guide channels is not very carefully studied. The channel forms selected in the present case are the result of extensive research work.

Axial compressors—The axial compressor has gained considerably in importance of late years. There can be no doubt that it will find even wider application in future, as some of its qualities can be turned to excellent account for many duties. If the axial compressor—in principle a very old invention—has only been put to practical use at a comparatively late stage of

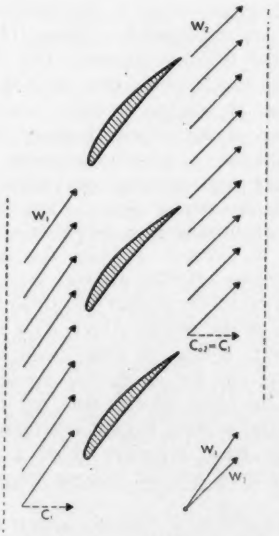


1 Runner blade
2 Diffuser blade
u Peripheral velocity of the runner
C_1 Absolute velocity of the air flowing to the runner
C_2, C_3 Absolute inlet and outlet velocities of the air relative to the runner
W_1, W_2 Relative inlet and outlet velocities of the air

Fig. 22. Diagram illustrating a single stage of an axial compressor.

technical development, this is because its aerodynamic design, as compared with that of the radial compressor, sets difficult problems which only an advanced scientific knowledge of aerodynamics has been able to solve. In the axial compressor, centrifugal force is no longer employed as a means of compression. Instead, use is made exclusively of the diffuser effect,, that is to say, the increase of pressure by the retardation of flow. This working principle at first sight appears anything but promising, and in fact it did not meet with success in the initial stages. Progress in aerodynamics, however, has finally revealed that the efficiencies attainable with this method are equal to and even higher than those attained with the radial compressor.

Fig. 22 illustrates the working principle of the axial compressor. At the top is shown a section through a single stage of the compressor, the runner blades being marked 1 and the stationary or guide blades 2. Below this is a developed section along the cylinder in the plane *I—I*, showing the sections and the arrangement of the blades. The arrow u indicates the peripheral velocity of the blades in this section, the arrow C_1 the velocity of the air approaching the runner wheel. It is clear from the parallelogram of velocities below that, in relation to the blades moving at the velocity u, the air flows into the runner at a velocity and in a direction represented by the arrow W_1. The slight curvature of the runner blades causes a small diversion of the flow of air as it passes though the blading, so that it emerges in the direction of arrow W_2. On the other hand, the velocity component in the direction of



W_1, W_2 Inlet and outlet velocities of the air relative to the runner
C_1, C_2 Axial components of the inlet and outlet velocities of the air relative to the runner

Fig. 23. Diagram illustrating the deflection and retardation of flow by a compressor runner.

the axis of rotation remains unchanged, since the quantity of air before and after the runner wheel is the same (see also Fig. 23). It follows from this that arrow W_2 must be shorter than arrow W_1. The flow is therefore retarded relative to the runner wheel, which in other words is nothing else but a rotary diffuser serving to raise the pressure of the air as it flows through.

The velocity W_2, like W_1, is measured relative to the moving blades. The corresponding absolute outlet velocity from the runner wheel—measured, that is, in relation to the casing—is C_2 (Fig. 22). It is also the inlet velocity to the following stationary blading, in which a further diversion takes place, till the air again flows in a purely axial direction at the velocity C_3. In order to take into account the reduction in the volume of the air due to compression, the inside diameter of the casing and with it the axial cross-sections in the direction of flow are continuously reduced. This reduction of cross-sectional area corresponds exactly to the increase in the density of the air, so that the axial component of the velocity remains in fact unchanged, as we have assumed, while the air passes through the blades. Thus C_3 is also smaller than C_2, and the stationary blading is simply a special design of diffuser in which the medium undergoes a further pressure increase in addition to the pressure increase taking place in the runner wheel. As a matter of fact, it may in some cases be advantageous to design the machine so that the axial velocity does not remain entirely constant, but this is a refinement of the basic principle which is of no importance for our present purpose.

It might at first glance appear necessary, when considering the processes taking place in the runner wheel, to observe the absolute movement of the air. This procedure would lead to the unexpected disclosure that the absolute velocity increases in the runner wheel from C_1 to C_2, and it might be concluded from this that the opposite of a diffuser effect has taken place. Such a conclusion, however, would be erroneous. It is actually quite possible to consider the absolute flow instead of the relative motion of the air, but in this case the forces which the blades exert on the medium as they pass through it must also be taken into account. This method of approaching the problem is much more complicated, but finally leads to exactly the same result as the simpler approach based on the relative flow.

The fact that the diffuser effect alone is used in the axial compressor narrowly restricts the pressure increase attainable in a single stage. Whenever a fairly high pressure is required, therefore, a large number of successive stages must be provided. Fig. 24 is a cross-section through a ten-stage Sulzer axial compressor. The runner blades are attached to a drum-shaped rotor, the stationary blades to a horizontally split blade carrier fitted in the casing. As the specific volume of the air diminishes with increasing compression, the cross-sections of flow must become smaller towards the delivery end. The length of the blades is reduced accordingly from the first stage to the last. The whole machine resembles a steam turbine with the direction of flow reversed.

The blading is not the only element which calls for detailed research work in compressors of this kind. The shaping of the inlet channels also demands careful aerodynamic study, and even more so that of the outlet. As the air leaves the last guide wheel at a fairly high speed, it must be slowed down in a diffuser, as otherwise its kinetic energy would be wasted. This diffuser is shown in Fig. 24 as a funnel-like outlet pipe.

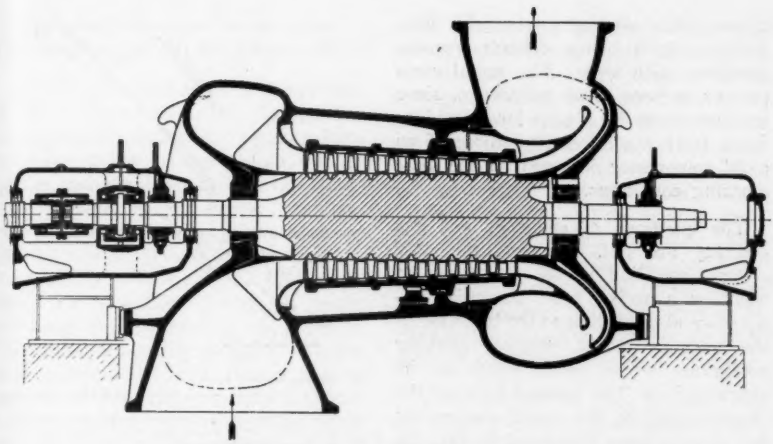


Fig. 24. Cross-section through a ten-stage Sulzer axial compressor

COMPARISON

In any comparison of the axial and the radial compressors, one point springs to the eye in the axial compressor the path of the medium to be compressed is simpler, shorter and has less sharp diversions. It is obvious that this in itself must lead to a reduction of the losses and an improvement of the efficiency. But it has proved in addition that the peculiar type of diffuser represented by the runner wheel of an axial compressor operates with particularly low losses. This fact is one which was not to be foreseen, but which gradually became clear in the course of research work carried out in aerodynamic laboratories. For these reasons the efficiency of the axial compressor is generally superior to that of the radial type.

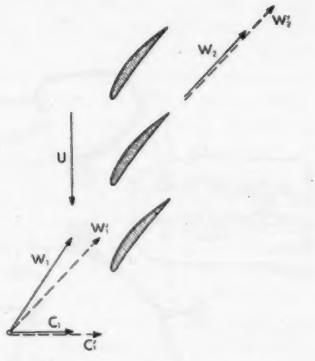
The complicated path followed by the working medium in the multi-stage radial compressor also entails considerably greater unit dimensions than would be necessary in an axial compressor designed to handle the same quantity of gas. This disadvantage becomes more pronounced when the attempt is made is find optimum designs for the channels of flow of the radial compressor. For while it is actually possible to design these channels to give an efficiency only very little inferior to that of the axial compressor, the diffusers then take up a great deal of space, and the resulting machine is disproportionately heavy and expensive.

It follows from this that the axial compressor is more suitable for handling large quantities of gas, while on the other hand small quantities can be better dealt with in the radial compressor. For as soon as the dimensions of the axial compressor are reduced below a certain minimum, it becomes difficult to generate sufficient pressure in a single stage without excessive losses of efficiency. The reason for this is that friction effects make themselves felt more markedly in machines of small dimensions, so that the action of the diffusers is generally less satisfactory. Such ma-

chines also demand extremely high speeds, which bring difficult gearing problems with them. The radial compressor is here at an advantage, since its dimensions are always larger and its speed is always lower than those of an axial compressor designed for the same working conditions.

The questions of efficiency and gas quantity are not, however, the only criteria applying to the choice of an axial or a radial type. Essential importance also attaches to the behavior of the machine under varying working conditions, or in other words to its characteristic. The general form of the characteristic of the radial compressor has already been illustrated in Fig. 14. The situation of the axial compressor is very different, as appears from Figs. 25 and 26.

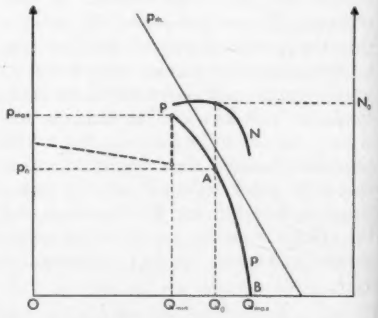
In Fig. 25 C_1 again represents the velocity of the air approaching the runner wheel, and U the peripheral velocity of the moving blades, so that W_1 the inlet velocity relative to these blades. The runner wheel then causes a deflection in the direction W_2, which, as already explained, involves a retardation and a pressure increase. Let us now assume, however, that the quantity of flow is increased by a small margin without any change in the peripheral velocity. The velocity of approach is then represented by the arrow C_1', and the relative inlet velocity becomes W_1'. If the direction of the arrow W_1' and the form of the blades are now closely observed, it will be seen from the diagram—and both theory and experiment confirm the fact—that under these circumstances no diversion of the flow can take place. The relative velocity W_2' at the outlet from the blading is then equal to W_1', so that there is no increase in pressure. If C_1' were a little greater still, the direction of W_1' would even be such that a diversion would take place in the opposite direction. In that case W_2' would be greater than



U Peripheral velocity of runner
W_1 Relative inlet velocity of air to runner at the absolute velocity of approach C_1
W_1' Relative inlet velocity of air at the absolute velocity of approach C_1'
W_2 Relative outlet velocity at the absolute velocity of approach C_1
W_2' Relative outlet velocity at the absolute velocity of approach C_1'

Fig. 25. Diagram illustrating the deflection of flow by the runner blades of an axial compressor with varying delivery.

W_1', and the result would be exactly the opposite of a diffuser action, i.e., the runner wheel would produce a drop in pressure. Exactly the same applies to the guide wheel. On the other hand, a slight reduction in the velocity C_1 of the air approaching the runner wheel



pth Theoretical pressure characteristic
p Actual pressure characteristic
N Input curve
Q Delivery quantity
A Normal service point
B Service point with no pressure and maximum delivery
P Surging limit

Fig. 26. Characteristic of an axial compressor.

would greatly increase the diversion in the wheel and with it the diffuser effect.

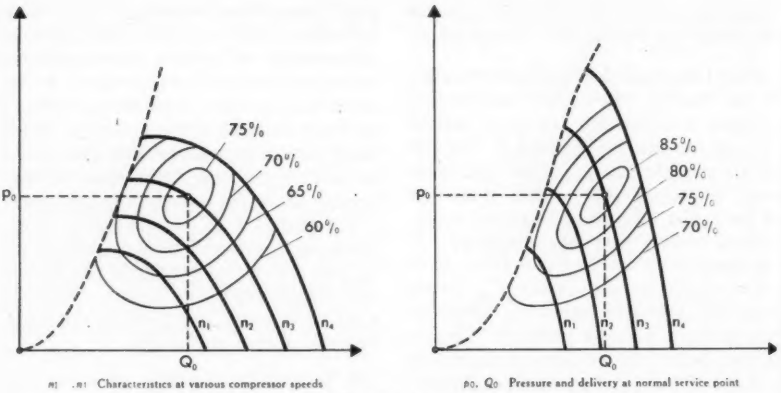
Exact theoretical analysis shows that, if all friction effects be disregarded, pressure and quantity are again related by a linear law represented in Fig. 26 by the straight line ρ_{th}. This line, however, is considerably steeper than that of the radial compressor because, as explained above, very slight changes in the quantity of flow per unit time, or in other words in the velocity C_1, deeply influence the generation of pressure. The pressure actually produced is again always below the theoretical figure on account of frictional phenomena, the difference between the two once more being smallest under the conditions of flow for which the machine is designed, i.e., at the normal service point A. It naturally becomes greater the farther the delivery moves from this point, in whichever direction. We thus obtain the curve ρ as the effective delivery characteristic of the axial compressor.

As already mentioned, a diffuser only works correctly when the medium flowing through it actually follows the bounding walls, in our case therefore the surface of the blades. If the deflection in the runner wheel becomes too great, this condition is no longer fulfilled, and finally a critical point is reached—point P in Fig. 26—at which the pressure suddenly drops off. This is the surging limit of the axial compressor.

The power requirements of the axial compressor depend on the fact that the diversion of the flow in the runner wheel creates reaction forces directed against the blades, which must be overcome by the driving unit. As a slight increase in the velocity of approach of the medium greatly reduces the degree of diversion, these reaction forces —and with them the input—decrease rapidly as the delivery quantity increases. In principle the input of the axial compressor therefore falls with increasing delivery. This reduction is less marked in practice than in theory, as again frictional forces have to be taken into account, and these increase with the velocity of flow. On the other hand, when the delivery is decreased to any extent, the influences of the greater diversion and the smaller quantity, together with all subsidiary influences, approximately balance each other, so that the forces acting on the blades and consequently the input remain almost unchanged. The result is the input curve N plotted in Fig. 26.

A comparison of Fig. 14 with Fig. 26 illustrates the fundamental difference between the characteristics of radial and axial compressors. Above all the pressure characteristic of the latter is very much steeper. When the speed of a compressor is fixed, its delivery is limited to a certain effective range stretching from the surging limit, i.e., the quantity Q_{min} in the diagrams of Fig. 14 and Fig. 26, to the point at which the pressure becomes nil, i.e., the quantity Q_{max}. The distance between Q_{min} and Q_{max} is much greater in the radial compressor than in the axial type. The former is therefore much more adaptable to fluctuations in the delivery quantity. On the other hand, the pressure of the axial compressor can be raised well above the value ρ_0 of the normal service point A, while the pressure increase possible in the radial compressor is only very small, as a comparison of the maximum pressures in the two diagrams at once reveals.

In considering these characteristics, we have so far assumed that the speed remains constant. If instead the speed is varied, a new pressure characteristic will have to be plotted for every speed. This gives us the general characteristic curves shown in Fig. 27, that on the left being for a radial and that on the right for an axial compressor. The lighter elliptical curves indicate the



$n_1 \ldots n_4$ Characteristics at various compressor speeds

p_0, Q_0 Pressure and delivery at normal service point

Fig. 27. Comparison of the general characteristics of radial and axial compressors.

efficiencies under the various working conditions.

A comparison of the basic differences between axial and radial compressors and of the other special features they each have to offer makes it quite clear that absolute superiority cannot be claimed for either type, but that a number of considerations will have a bearing on the selection of the best type for any given duty. Among other things, the means of regulation must also be taken into account.

The advantages of the axial compressor are still little known in many branches of industry, and it is therefore to be expected that this machine will find numerous new applications in coming years. It should be of particular interest to the smelting industry, as it is highly suitable for producing air blast. The large quantities of air required for blast furnaces bring very high compressor inputs with them, and the recent tendency to build bigger blast furnaces only emphasizes this fact. Under these circumstances the good efficiency of the axial compressor gains greatly in importance, while its steep characteristic and its consequent pressure reserve are likewise strong points in its favor. At times when hanging of the charge occurs in the furnace, this compressor type enables the air to be forced through at much higher pressure, so that the trouble is quickly remedied.

The apprehension is sometimes voiced that the axial compressor is too delicate and sensitive for the rough service of smelting works. Such misgivings are unfounded. The axial compressor is no more sensitive mechanically than the steam turbine, which has long been used with success in the smelting industry. The sensitivity of axial compressor blading to fouling has likewise been frequently exaggerated.

It is clear from the above remarks that the selection of the correct compressor type for a given application is not a simple matter. It raises a number of problems which are often of a complex nature and can only be satisfactorily solved by close collaboration between manufacturers and purchasers. The earlier such collaboration begins, the longer will be the time available for the conscientious investigation of all the questions involved, and the firmer will be the guarantee that the solution found is both technically and economically the best possible one.

COMPRESSORS FOR AIRCRAFT GAS TURBINES

ACKNOWLEDGMENT

This article was published in the December 15, 1950 issue of "Engineering." The drawings are from the December 14, 1950 issue of "Flight," which contained an article on the same discussion. The article is a report of a debate before the Royal Aeronautical Society on the relative merits of centrifugal and axial compressors for aircraft gas turbines. This article should be compared with the Sulzer article "Radial versus Axial Compressors," also reprinted in this issue of the JOURNAL, inasmuch as they point up the areas of agreement and disagreement between the Swiss and British points of view.

A discussion on the relative merits of centrifugal and axial compressors for aircraft gas turbines was held on Thursday, December 7, at a meeting of the Royal Aeronautical Society, with the President, Major G. P. Bulman, in the chair. The case for the centrifugal compressor was stated by Dr. E. S. Moult, B.Sc., M.I.Mech. E., F.R.Ae.S., supported by Mr. J. L. P. Brodie, M.I.Mech. E., A.F.R.Ae.S., both of the de Havilland Engine Company, Limited; and for the axial-flow compressor by Mr. H. Pearson, B.A., A.F.R.Ae.S., with Mr. A. C. Lovesey, O.B.E., B.Sc., F.R.Ae.S., of Messrs. Rolls-Royce Limited.

Dr. Moult, who opened the discussion, said that the axial compressor was more efficient at its design condition, but axial blading was very sensitive to changes in incidence; in flight, a wide range of loads and speeds must be covered. In the interests of stability, there must be some sacrifice of efficiency at certain points. Experience had shown that the centrifugal compressor would maintain a high efficiency over its whole working range, and it was less susceptible to the effects of Reynolds number than the axial compressor which might lose 5 or 10 percent in efficiency between sea level and 40,000 ft. altitude. The diameter of the conventional centrifugal compressor was usually larger, for a given rate of air flow, than that of the corresponding axial unit. In some installations this would not matter; for example, to give the necessary room for pilot, guns, etc., the diameter of the Vampire fuselage could not be reduced. Recent developments showed that it was possible at least to halve the frontal area of existing centrifugal compressors for the same through-put.

The best results from a gas turbine were, he said, attained only when the compressor and turbine reached their peak efficiency simultaneously. The sharp characteristics of the axial compressor made this matching process more difficult, and an axial compressor might have to be re-bladed many times before achieving the desired performance. For most compressors, the point of maximum efficiency lay near the

surge line, and for the axial compressor it was difficult to steer a safe course between instability and efficiency. To pressurize the cabin or to de-ice the airframe it was convenient to bleed-off air from the compressor. This was straightforward up to about 10 percent of the flow with the centrifugal impeller, but was much more critical with an axial compressor. The cost of the axial-flow compressor was perhaps twice that of the corresponding centrifugal type, mainly due to the problems of manufacture, extremely fine limits were essential for good performance. The centrifugal impeller was practically unaffected by vibration, dirt, snow or ice, and continued to give unimpaired performance after many hundreds of hours' service. Axial compressors were much more susceptible to these effects; losses of 5 to 10 percent had been experienced in the course of a 150-hour type test. Vibration problems were much more complex for the axial compressor; to avoid all the resonant frequencies on all the blades over the whole speed range was well-nigh impossible. Because of its speed and working temperature, ice would not stick to the centrifugal impeller in quantities likely to affect its performance; it could, in fact, accept quite large lumps of ice.

Mr. H. Pearson said that test results showed that at almost any compression ratio up to 7 to 1, the axial compressor gave 7 percent better efficiency. The reason, he thought, was that the axial compressor imparted some velocity to the air, which was then changed to pressure, and the process was repeated, preserving reasonable velocities relative to the rotating parts, whereas the centrifugal compressor tried to give all its velocity in one stage and attempted to change that high velocity to pressure, with very high losses. The axial compressor passed some three or more times as much air as the centrifugal compressor of the same frontal area. Even if, on a centrifugal installation, diffusion were carried out axially, the centrifugal compressor would be only half as good as the axial compressor.

Weight, he said, was a difficult subject to discuss logically; it was easier to consider the bulk of a compressor. He had, therefore, plotted the useful power divided by the longitudinal-sectional area through the compressor, i.e., its length multiplied by diameter. This gave a method of comparing compressors independently of their size, avoiding the square-cube law. On this basis the axial compressor was shown to be twice as good as existing centrifugal installations, and 50 percent better than they could eventually achieve. The supersonic axial compressor would ultimately put the centrifugal engine out of existence; some large sacrifices in efficiency might have to be made, but the frontal area would be much smaller and the bulk about one-seventh. Discussing the ability of the compressor to operate satisfactorily away from its design point, he claimed that if the turbine-outlet conditions were considered, axial and centrifugal compressors showed comparable characteristics. The axial compressor could be split up into stages, and the performances analyzed and even tested separately. Rig tests on cascades of blades representing the turbine and compressor blades could be carried out without serious discrepancy, and although this technique was not directly applicable to the three-dimensional problem, it had enabled a thorough knowledge of the behavior of the blading to be acquired. No such analysis was possible for a centrifugal impeller, because each part of the engine required the presence of the others for correct functioning. Moreover, all the concepts and methods of wing theory were readily carried over to axial-compressor blade rows, whereas in the centrifugal impeller progress depended upon a large number of *ad hoc* tests.

Mr. J. L. P. Brodie said that the axial compressor, with its many small

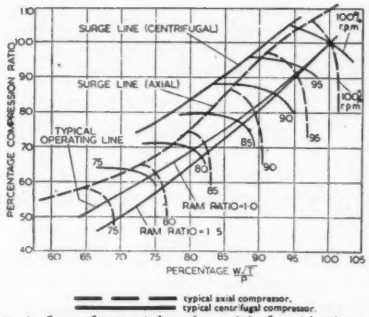


Fig. 1. Curves of pressure/volume characteristics for axial and centrifugal compressors of equal pressure-ratio. The mass-flows have been adjusted to correspond at 100 per cent. r.p.m. (Moult.)

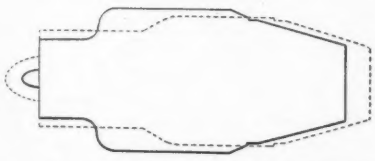


Fig. 2. Comparative outlines of a typical axial and a possible centrifugal power unit of equivalent air mass-flow and thrust (Moult.)

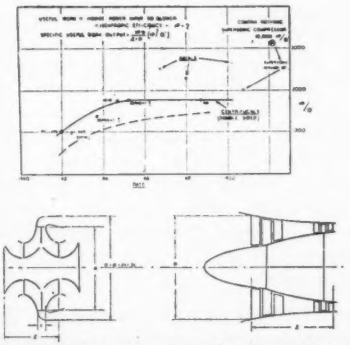


Fig. 3. (Above) Comparative curves of useful work on the basis of useful power divided by cross-sectional area of the compressor. (Pearson.)

accurately-manufactured blades and discs, was expensive in man-hours, factory space and capital equipment. Close-to-size forging was probably the most economical method of producing small axial-compressor blades. For a compressor of, say, 12 stages, by duplicating the blade forms as frequently as possible throughout the engine and cropping them to suit their individual stages, at least 16 sets of dies, costing between 500*l.* and 600*l.* each, would be required. The estimated production from each die would be, roughly, 3000 in aluminum, 1500 in aluminum bronze, and between 300 and 500 in stainless steel. The cost of the blades would vary between 5*s.* and 3*l.* each. They would require machining on the root attachment and on the leading and trailing edges and tips, involving 0.25 to 0.50 man-hour per blade. The die for centrifugal-compressor blading would probably cost some ten times more, but it had a life of some thousands of forgings; the limits of accuracy on the centrifugal blade forms were much lower. In this country little had been done yet to develop special machine tools for handling large quantities of axial-compressor blades with the necessary accuracy. The vulnerability of the axial compressor was, and would probably remain, its greatest weakness. The drop in performance due

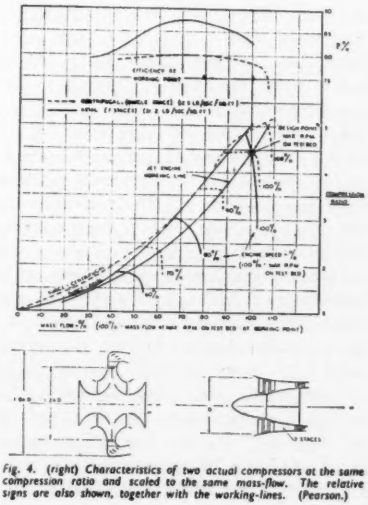


Fig. 4. (right) Characteristics of two actual compressors at the same compression ratio and scaled to the same mass-flow. The relative signs are also shown, together with the working-lines. (Pearson.)

to fouling in use of the compressor was higher for the axial-flow type. Cleaning methods were being developed, but they did not reduce the erosion of the blade surfaces after many hours of operation; a decreasing return was obtained from each subsequent cleaning.

Mr. A. C. Lovesey said that, although less development time had been spent on the axial-flow engine than on the centrifugal type, the axial engine was far more efficient under all conditions. This statement was based on some precise flight-testing data which had been obtained on both types, over a wide speed range and at altitudes higher than 50,000 ft. The axial engine gave an average specific fuel consumption lower by 17 percent. Due to the difference between the specific consumption and the drag of centrifugal and axial engines of equal thrust, an aircraft which had been fitted with both types showed a range reduced by at least 20 percent with the centrifugal installations. Two engines, one of each type, had been developed by the same design team. Both engines gave a specific weight of 0.282 lb.-weight per pound-thrust, and both operated at the same flame temperature, but the axial engine gave 70 percent greater thrust per square foot of frontal area. Axial-flow engines were being flown today with far better flexibility and handling characteristics than any centrifugal engine. Acceleration times, from idling to maximum thrust, of 5 seconds on the ground and 3 to 4 seconds in flight were being obtained. The reliability of the axial type was just as high as that of the centrifugal type, and the axial compressor was kinder to the combustion equipment. It had been found to be not much more vulnerable to the effects of ice and other foreign bodies. Simulated icing tests were carried out in flight by spraying water into the intake of an axial compressor; this resulted in ice building up on the inlet stator vanes, giving a 20-percent loss of thrust. Measures were being taken with surface heating to overcome the trouble. The engine was not vulnerable to large lumps of ice, which frequently became detached during the test. The axial compressor, in development, was much more costly than the centrifugal type, but the cost would come down rapidly as production increased. Blades could now be pressed to size, instead of being forged.

In the general discussion which followed, Major Halford pointed out that there were no axial jet engines in service in the Royal Air Force today, and that if war were to break out tomorrow, it would be fought largely with centrifugal machines throughout the world. The axial design had to be much cheaper and easier to make. Mr. Lovesey, he said, had not stated how long it took to warm up the axial engine to idling speed. The next speaker, Mr. F. M. Owner, said that the space available in the aircraft was getting steadily smaller. An engine, he thought should not be much larger than 1 meter in diameter, whatever its output. There was no possibility of getting even a two-stage centrifugal-type engine of 10,000 lb. thrust into that diameter. Moreover, for increasing its specific output, the compression ratio and the component efficiency of a jet engine must be raised. The two factors of increasing speed with increasing output, and the increased compression ratio, made the development of pure axial-flow compressors essential, whatever the difficulties to be overcome.

Mr. L. J. Cheshire said that there was no question that the centrifugal design was simple to produce, which might soon be a vital consideration. The development of the centrifugal compressor ought not, therefore, to be dropped; some attention should be paid to its aerodynamics, which had been neglected in this country and America. The next speaker, Mr. H. Constant, did not agree that further work should be done on

the centrifugal compressor. He considered that the axial compressor was 15 percent more efficient than the centrifugal, and that in frontal area the ratio was two to one in favor of the axial-flow type; he thought also that it was as light as the centrifugal form. Probably not more than two of the four factors—lower weight, better fuel consumption, better thrust per unit frontal area, or lower cost—could exist simultaneously.

Dr. H. Roxbee Cox thought that there was probably a place for both types of engine, the axial compressor engine for very high thrusts and the robust, reliable and easily-produced centrifugal engine for smaller sizes and for civil use. It would be wrong, therefore, to neglect the development of the centrifugal compressor. His views were shared by the speaker who followed, Mr. G. R. Edwards, who thought that the centrifugal compressor derived its reliability from its development from the well-established centrifugal supercharger. Vulnerability to impacts was, he suggested, largely a function of blade size. A high-performance long-range aeroplane had to be small, with limited room for the engines and fuel. A subsequent speaker, Mr. S. Butler, said that in this country a die-life of 1000 stainless-steel blades had been achieved. The forging industry had not yet been put to the test of producing cheap blades for axial compressors. The following speaker, Mr. C. M. Wilde, attributed the lower efficiency of the centrifugal impeller to the high Mach numbers at which it had to be run, and the consequent high losses in the diffuser. He thought that unless diffusers could be designed more efficiently, there was no hope of operating a centrifugal impeller at a pressure ratio greater than 4 to 1.

Replying to the discussion, Mr. Pearson said that he did not agree that variations in Reynolds number had a more adverse effect on axial compressors; flight tests suggested that the axial compressor might, in fact, be better in this respect. The large axial compressor could be made as reliable and invulnerable to impact damage as the centrifugal compressor.

Dr. Moult, in his reply to the discussion, said that some discretion must be used in interpreting all the figures put forward. An axial-flow engine developing 30 lb. thrust per square foot of frontal area had been mentioned; his impression was that current axial machines had achieved half that figure. He had shown a centrifugal engine which had developed 14 lb. thrust per square foot, which did not compare badly with the axial engine. The value of efficiency, he thought, could be overrated. Rockets, ram-jets, and re-heat were all most effective used in their proper sphere. As the speed of flight increased the gap between the test-bed efficiencies of axial and centrifugal compressors was narrowed by the effect of ram compression, which with a good intake raised the level of overall compression efficiency.

In summing up the discussion, the President said that British jet engines could still be said to be the best in the world, largely because there had been no idea that there was only one right way. He had hoped that more would have been said about production. Those who had to decide policy might be right in allotting a very large proportion of the design and development effort to the axial engine and its application to prototype aircraft. It was no good having very fine engines on paper or in a few prototypes if they could not be made in quantity at the right time. Therefore he hoped that attention was being given not only to efficiency, but also to the production side.

DENNY-BROWN STABILIZING GEAR IN THE P. AND O. TWIN-SCREW PASSENGER LINER "CHUSAN"

ACKNOWLEDGMENT

This article was published in the December 29, 1950 issue of "Engineering." It describes the Denny-Brown stabilizing gear in the British ship *Chusan*.

The entry of the twin-screw passenger and cargo liner *Chusan* into the Far-Eastern service of the Peninsular and Oriental Steam Navigation Company marked the end of the owners' post-war passenger-vessel building program. Built by Messrs. Vickers-Armstrongs Limited, at their Barrow-in-Furness yard, the *Chusan* is the largest passenger liner to be completed anywhere in the world during 1950. The vessel was ordered in May, 1946, the keel was laid in February, 1947, and on June 25, 1949, she was launched by Viscountess Bruce, wife of the Rt. Hon. Viscount Bruce of Melbourne, who is a director of the P. and O. Company. The *Chusan* was completed by June, 1950, and after her trials, left on a series of cruises before joining the *Carthage*, *Canton* and *Corfu* in the Far Eastern service.

The most interesting technical feature of the *Chusan* is, undoubtedly, her Denny-Brown stabilizing gear. This gear, which is designed and manufactured by Messrs. Brown Brothers and Company, Limited, Rosebank Ironworks, Edinburgh, in association with Messrs. William Denny and Brothers, Limited, Dumbarton, is, of course, not new as, during the war, many vessels of the destroyer and escort class were so fitted. Some cross-channel packets also have been equipped, notably the Maid of Orleans, built by Messrs. Denny for British Railways, Southern Region, and put into service in June, 1949, but hitherto the largest ship provided with stabilizers had a displacement of some 3000 tons, whereas the *Chusan's* displacement is approximately 26,000 tons.

In general, the type of stabilizing gear fitted to the *Chusan* is similar to the earlier smaller installations. It consists of two rectangular fins of aerofoil section, disposed one at each side of the vessel and projecting from the hull in the vicinity of the bilges. The fins are arranged so that they can be retracted into the hull of the vessel; when extended, they lie in the natural streamline and offer, therefore, very little resistance, acting as extra bilge keels. A photograph showing the starboard fin extended is reproduced in Fig. 35. Each fin is mounted on a shaft in the same manner as a balanced rudder, but with the shaft approximately horizontal

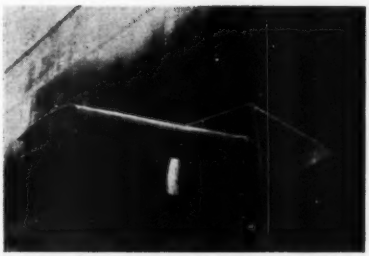
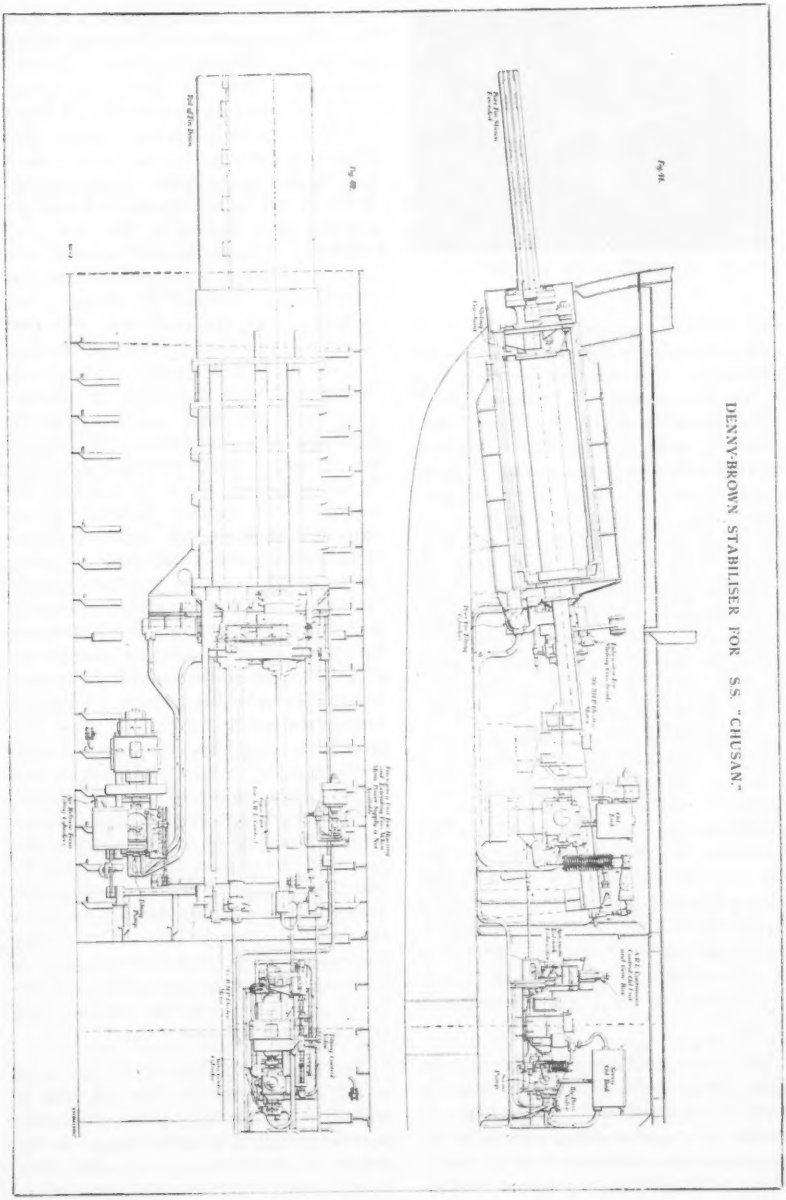


FIG. 35.—Starboard fin in extended position

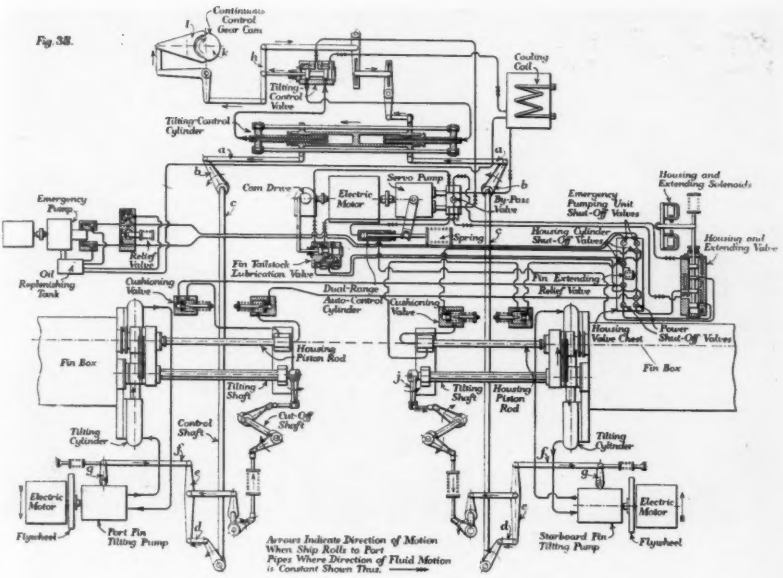
and the axis disposed so that the fin is hydrodynamically balanced; the torque required to produce angular movement of the fin, therefore, is relatively small. To stabilize the vessel, the fins are tilted about the axes of their shafts, the controlling and operating mechanism being synchronized so that their angular movements are equal and opposite. In the case of the ship being rolled to starboard by wave action, the fins are set so that the starboard fin has a positive angle of attack and the port fin a negative angle of attack. The forward velocity of the ship causes the water to exert an upward force on the starboard fin and a downward force on the port fin, thereby setting up a righting couple which counteracts the force tending to cause rolling. Obviously, a rapid reversal of the fins is necessary at the completion of each roll to obtain the maximum righting moment on the hull and, in the *Chusan,* this reversal takes place in 1½ seconds, during which period the fins may move through their maximum angle of 40 deg.; this may be contrasted with the 30 seconds usually required to move a rudder through 70 deg.

Hydraulic machinery is employed for tilting the fins and retracting them inside the hull. The mechanisms for the port and starboard fins are exactly the same, but to opposite hands; drawings showing elevational and plan views of the port stabilizing gear are reproduced in Figs. 41 and 42, respectively, and the complete hydraulic system, together with the associated mechanical linkages, is shown diagrammatically in Fig. 38. Power for tilting the fins is supplied by two size 24 Mark III VSG variable-delivery pumps, each driven by a 50-hp. electric motor; and a size 6 Mark III VSG pump, known as the servo pump, supplies power for housing and extending the fins and operating the tilting-gear control cylinder. The tilting movement of the fins is controlled by small gyroscopes; two of these units are used, one of which measures the rolling velocity of the ship and the other the angular displacement, the outputs being combined in any desired ratio to effect the best control. The forces developed by the gyroscopes are, of course, small and therefore have to be amplified. This is achieved by means of a sensitive hydraulic-motor unit developed by the Admiralty, the signals being transmitted from the gyroscopes to the hydraulic unit by a system of "magslips." The magslip is, of course, well known as a device for the electrical transmission of angular displacements and, by using senders and receivers, it is possible to transmit such movements over considerable distances. The displacement gyroscope is provided with two magslip transmitters, either of which can be connected through a suitable switch to a further magslip transmitter operated by the velocity gyroscope. By this means it is possible to add the motions of the two gyroscopes algebraically, the sum being passed to the hydraulic-motor unit, which copies the motion with sufficient increase in power to operate a cam. The cam follower is connected to the control valve of the hydraulic tilting gear.

The cam and follower are lettered *k* and *l,* respectively, in Fig. 38, and it will be noted that the follower is connected through a suitable linkage to the piston of the tilting control valve. This valve admits oil from the servo pump to one side or the other of the tilting-



DENNY-BROWN STABILISER FOR S.S. "CHUSAN."



control cylinder which, together with the servo pump, forms the servo-power unit. It will be seen from Fig. 38, however, that the tilting-control cylinder is divided by a transverse central plate into two separate cylinders, each of which contains a piston drilled along the center line to allow entry of the pressure oil. The two pistons are stationary, their outer ends being fixed to the supporting framework of the servo power unit, whereas the cylinder assembly is free to move horizontally. The tilting control valve is designed so that, when one cylinder is opened to the servo-pump delivery, the other is automatically connected to the servo oil tank, the cylinder assembly moving to the right or left according to the direction of flow of the oil.

The movement of the cylinder barrel is transmitted through a system of links and levers to the swashplates of the two pumps which deliver oil to the fin tilting rams, the linkages operating the port and starboard fins being identical but, of course, to opposite hands. The action of the linkage can be followed by reference to Fig. 38, from which it will be seen that the cylinder barrel is provided with lugs connected by the pull and push rods *a* to the levers *b* integral with the torsion shafts *c*, the levers converting the linear motion of the cylinder into rotary motion of the shafts. Further levers fitted to the opposite ends of the shafts are connected through the links *d*, *e* and *f* to the levers *g* which are keyed to the operating shafts of the pump swashplates. Any movement of the control cylinder therefore causes a corresponding movement of the pump swashplates.

Hunting gears are fitted to the control cylinder and both fin-tilting pumps; otherwise it would not be possible to

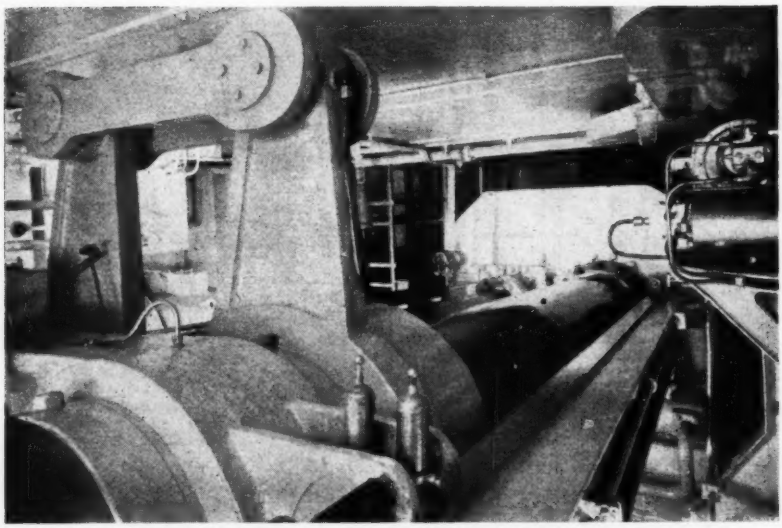


FIG. 39.—Tilting mechanism for port fin installed in vessel

get movement of the fins in proportion to the signal transmitted by the gyroscopes. The hunting gear for the control cylinder is shown in Fig. 38, from which it will be seen that one end of the arm *h* which operates the tilting control valve is connected by a linkage to the body of the control cylinder. When the valve is actuated by the gyroscopic-control unit, the subsequent movement of the control cylinder is transmitted through the linkage back to the arm *h* and moves the valve in the opposite direction to that imposed by the gyroscopes, thereby returning it to the closed position. For the tilting pumps, the hunting gear in each case is operated by a lever keyed to the end of the fin-tilting shaft. The lever for the starboard hunting gear is lettered *j* in Fig. 38, and it will be seen that it is connected by a system of shafts and levers to the arm *e* of the pump control linkage, the system of shafts and levers being arranged so that movements of the fin in response to the pump automatically returns the pump lever *g* to the neutral position. Those who know Messrs, Brown Brothers' electro-hydraulic steering gear will realize that the stabilizer mechanism bears a close resemblance to that gear, the gyroscopic-control unit taking the place of the helmsman and the control cylinder the place of the telemotor receiver.

The tilting gear for each fin consists of a pair of opposed cast-steel cylinders fitted with a single double-ended ram, each assembly being bolted to the inboard end of the box-like structure which houses the fin in the retracted position. Fig. 47 shows the linkage which transmits the motion to the fin shaft. The linkage can also be seen in Fig. 36, which shows the operating gear for the port fin erected in the shops of Messrs. Brown Brothers; and in Fig. 39, which shows the gear erected in the *Chusan*. As will be seen from Fig. 47, the piston is connected through a Rapson slide to the fixed tilting lever. This is keyed to the

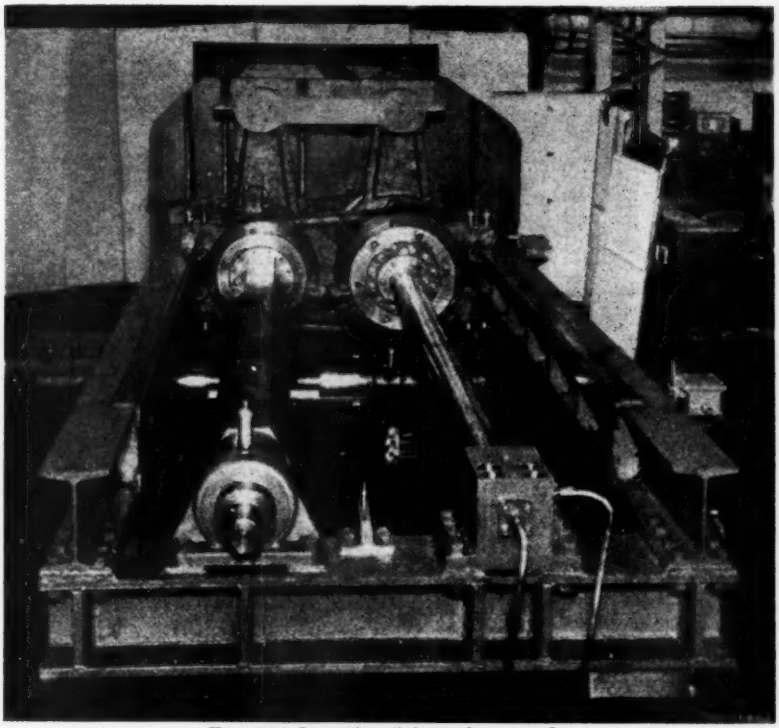
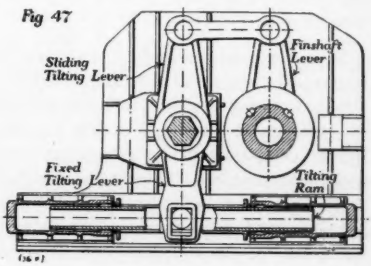


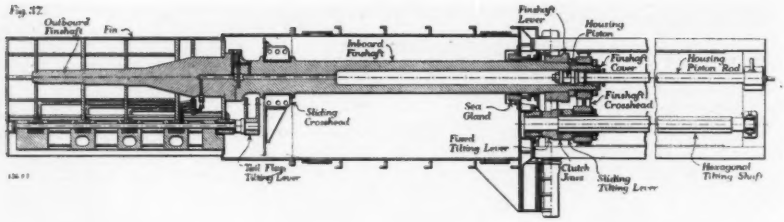
FIG. 36.—Operating linkage for port fin

tilting shaft and is joined to the sliding lever through a dog clutch, one half of which is integral with the fixed lower lever and the other half with the upper sliding lever. The motion is, in turn, transferred to the fin-shaft lever by the top link, the fin-shaft lever, of course, being secured to the fin shaft.

The term "sliding" is used in connection with the upper lever owing to the fact that, during retraction or extension of the fin, it moves, together with the fin-shaft lever, to the inboard position. In Fig. 39, the fin is in the retracted position; in Fig. 36, the fin is in the extended position and the dog clutch is engaged, thereby rendering the fixed and sliding levers virtually solid. Retraction and extension of the fins is carried out hydraulically and the

Fig 47





method by which this is achieved can best be understood by reference to Fig. 37. This shows a plan view of the port fin in the extended, or working position, and it will be noted that the fin shaft is in two parts, a solid outer portion being bolted to an inner portion bored out to form a cylinder. The shaft was made in two parts to facilitate installation, as this had to be carried out in a dry dock after the vessel had been launched. The outboard end of the fin shaft is supported in a sliding crosshead arranged to run in guides secured to the inside of the fin box and, at the inner end, the shaft passes through, and is located by, a gland assembly. The cylinder formed in the inner portion of the shaft is fitted with a piston, the rod for which is anchored to the ship's structure so that if oil under pressure is admitted, to the right hand side of the piston, as viewed in Fig. 37, it will react against the "cylinder" cover and move the fin shaft to the right, thereby causing the fin to be retracted. Conversely, once the fin has been retracted, admission of oil to the left-hand side of the piston will cause the fin to be extended.

Housing and extending the fins is controlled by small electric switches situated on the bridge and a further set of switches is arranged inside the stabilizer compartment to give local control when required. Operation of either the housing or extending switch energizes one of a pair of solenoids and, by means of the housing-control valve, admits fluid from the servo VSG pump to either side of the housing piston in accordance with requirements. To prevent "bumping" of the fin shafts at each end of the stroke, tappet-operated cushioning valves, designed to slow down the last 3 in. of movement, are incorporated between the control valve and the housing piston.

In practice, two ranges of pressure are used in the hydraulic system, namely, between 600 lb. per square inch and 1100 lb. per square inch for housing and extending the fins, and between 220 lb. per square inch and 400 lb. per square inch for operating the tilting gear. To give the two different pressure ranges, the servo pump is fitted with a control; this is shown diagrammatically in Fig. 38, from which it will be seen that it consists of a piston opposed by a spring, the piston rod being arranged to operate the swashplate of the servo pump. The underside of the piston is connected directly to the delivery side of the pump and, when the pressure rises above a predetermined level, the spring is compressed and the tilt of the pump swashplate reduced with consequent reduction of discharge. Any fall in pressure, on the other hand, causes the spring to extend and increase the output from the pump. The two ranges of pressure are obtained by connecting the right-hand side of the piston, as viewed in Fig. 38, either to the delivery from the pump or to atmosphere. The higher pressure range is obtained in the former case as the effective area on which the

Fig. 48.

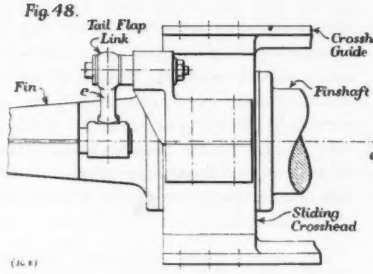
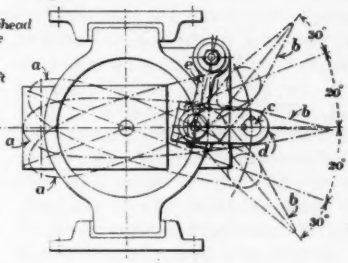


Fig. 49.



fluid acts for compressing the control spring is only that of the piston rod and it will be apparent that, when the right-hand side of the piston is open to atmosphere, the low-pressure range will be obtained. Operation of the housing-control valve automatically sets the servo VSG pump to the high-pressure range when housing and extending the fins and returns it to the low-pressure range when either of these two operations are completed. A separate variable-delivery pump, driven by a 2-hp. motor, is incorporated in the hydraulic circuit for housing and extending the fins when the main power supply is not available.

To keep the dimension of the fin to a minimum and, at the same time, obtain maximum possible lift from a minimum angle of movement, a special design of fin is employed. Briefly, it consists of two parts, the main portion being fitted to the finshaft and tilting about the center of the shaft, and a tail flap hinged to the trailing edge of the main fin and operated by a system of links designed so that its angular movement is always greater than that of the main fin. The action of the linkage will, possibly, best be understood by reference to the diagram reproduced in Figs. 48 and 49, in which the main fin is lettered *a* and the tail flap *b*. The shaft *c* is solid with the tail flap and has keyed to it the arm *d* which, in turn, is connected to the base of the swinging link *e*. The top of the swinging link is anchored to the outer face of the crosshead, which serves to locate the main fin shaft. If the fin is given, for example, a negative angle of attack, the arm *d* will react against the base of the swinging link and cause the tail flap to take up the position shown. Conversely, if the fin is given a positive angle of attack, the action of the tail flap will be reversed. As will be seen from the diagram, the tail flap is moved through an angle of 30 deg. in relation to the main fin.

As previously mentioned the operation of the hydraulic tilting machinery is determined by the gyroscopes working in conjunction with a hydraulic motor unit. This is known as the A.R.L. continuous-control unit and comprises a small, exceptionally sensitive oil unit which drives the tilting-control cam through a gearbox. The oil unit consists of an electric motor arranged to drive a hydraulic pump at approximately 600 rpm., the pump being designed to give more or less constant pressure regardless of the output. On the same axis as the pump, but mechanically separated, is a similar unit which serves as a hydraulic motor, while between them is a valve designed so that, if it is moved in one direction, oil is admitted to the hydraulic motor to cause clockwise rotation of the output shaft and, when it is moved in the opposite direction, causes anticlockwise rotation of the shaft.

Above the pump and motor is a casing on which are mounted two magslip units, namely a hunter which works in conjunction with the magslip transmitters in the gyro unit, and a resetting magslip. The hunter magslip is provided with an arm approximately 1 in. long; this operates a pilot valve movement of which causes oil to flow into small relay cylinders. These, in turn, control the movement of the valve situated between the hydraulic pump and motor. When the gyroscopes are at rest, the transmitters in the gyroscope unit hold the hunter in its central position and the hydraulic motor remains stationary. Movement of either the displacement gyroscope or velocity gyroscope, however, operates the associated magslip transmitter and causes the hunter to follow and initiate movement of the hydraulic motor and, therefore, the tilting-control cam. The output shaft of the hydraulic motor is also coupled to the rotor of the resetting magslip, which is so arranged that, as the motor moves in response to the hunter, the signal from the resetting magslip opposes that from the gyroscopes and returns the hunter to its central position.

To appreciate the reason for using both displacement and velocity gyroscopes, it is, perhaps, best to consider the vessel rolling in a beam sea and a following sea, respectively. With a beam sea, the tendency is for the vessel to roll heavily in her own period and in these conditions experience has shown that roll damping, in preference to an attempt to keep the vessel upright, is the best means of control. Roll damping may be expressed as a control which opposes the velocity of roll at any moment and implies that the tilt of the fins should be changed over at the extreme position of roll, that is, when the rolling velocity is zero. If this were effected from the velocity gyroscope alone, a pause would occur due to the inherent lag in the fin-tilting gear and part of the stabilizing time would be lost. By combining with the roll velocity an opposed-roll vertical signal from the displacement gyroscope, however, the reversal of the fins can be rendered more precise, the signal being transmitted to the fin-operating gear before the true changeover of the roll velocity of the vessel.

In following-sea conditions, however, the vessel may experience a long slow yaw roll and be held at the heeled-over position for an appreciable period of time, and the angular velocity, as a consequence, may fall to a value insufficient to affect the velocity gyroscope. If a velocity gyroscope only is used, therefore, the fins will center and cease to counteract the motion of the vessel. This action is prevented, however, by the displacement gyroscope, the signal from which is added to that from the velocity gyroscope and acts to prevent the fins from centering until a positive angular velocity in the opposite direction is built up. It will be clear that, to meet the different types of rolling induced by beam seas and following seas, the signal from the displacement gyroscope has to be reversed; it is for this reason that it is provided with two magslip transmitters, the connecting linkages being arranged so that they are rotated in opposite directions for any given displacement of the gyroscope. A change-over switch is provided on the navigating bridge and the selection of either control is left to the discretion of the navigating personnel.

The gyroscopes and their associated magslips are arranged so that either a tilt of 3 deg. from the vertical, as measured by the displacement gyroscope, or an angular velocity of 2 deg. per second, as derived from the velocity gyroscope, gives full fin angle tending to right the ship. Smaller angles of roll and roll velocity produce proportion-

ally less fin movement and any combination of these values will produce a signal to effect movement of the controlling cam. For example, a tilt of 6 deg. to port and a roll velocity of 4 deg. per second towards the midships position will cancel each other; the cam, as a consequence, will give a zero signal and the fins will remain in the neutral position. A roll velocity to port of the same value and under the same conditions of tilt, however, would give a movement of the cam corresponding to four times the full fin signal. To counteract this, the cam, once it moves past the full signal position, is circular and the signal passed to the fins, therefore, does not increase. The cam, therefore, has two functions, namely, to control the fins in accordance with the signal transmitted by the gyroscopes and to absorb those excess movements which cannot be translated into fin movement.

The velocity gyroscope is arranged so that the axis of the wheel is disposed horizontally and the casing is free to swing about the vertical axis. The vertical axis is integral with the ship and any roll imposed on the vessel precesses the gyroscope, this precession being limited by spiral springs which restrain the movement in proportion to the velocity of roll. This movement is transmitted by the sector of a gearwheel integral with the casing, which meshes with another wheel fitted to a vertical spindle. The spindle is provided with a suitable damping device and at its upper end is fitted with an arm which transmits the movement of the gyroscope to the magslip transmitter. The vertical-keeping or displacement gyroscope is vertical and its casing is carried by bearings fitted to a horizontal gimbal supported by two pedestal bearings. Two links with ball-and-socket joints are secured to the gimbal and these are connected to the two magslip transmitters which give beam and following-sea control, respectively. The gyroscope casing is "bottom-heavy" and functions, therefore as a long-period pendulum.

Before the fins were fitted to the *Chusan,* an endurance trial was held at Barrow, the operation of the fins being controlled by the dock-trial gear. With the tilting gear moving from hard-over to hard-over in approximately 1.8 seconds and with a 15-second period, the machinery was run for 28½ hours, in which time the performance was quite satisfactory. Running temperatures remained low, the final temperature being: starboard main pump, 116 deg. F.; port main pump, 122 deg. F.; and the servo pump, 103 deg. F. Sea trials were carried out while the vessel was proceeding from Liverpool to the Clyde for her speed trials. As the weather was not suitable for demonstrating the stabilizing effect, the action of the gyroscopes was reversed and the stabilizer used to impose a forced roll. These further trials were also successful. The roll imposed on the ship exceeding expectations and, during the final run at 20 knots and $\pm$ 20 deg. fin angle, the forced rolling was stopped, by changing over the action of the stabilizer, before the maximum angle of roll had built up. During these tests, the ship's roll was measured by a gyroscopic roll recorder and the records obtained showed a distinct difference between a forced roll allowed to decline naturally and a forced roll corrected by the stabilizing gear. During the vessel's speed trials, two runs on the measured mile were carried out with the stabilizer fins extended but not operating, and, when compared with equivalent runs but with the fins housed, no reduction in the speed could be observed. As the weather gave no opportunity for testing the stabilizing effect of the gear, recourse had to be made again to forced

rolling. Two runs were made, in the first of which the fin angles were limited to ± 16 deg. while for the second run one fin was housed and the other left extended, to demonstrate the practicability of stabilization with one fin only. With both fins in operation, the ship's roll was 28 deg. and with only one fin operating, 21 deg. 30 min., the fin movement in the latter case being ± 20 deg. We understand that experience in service has fully confirmed the satisfactory functioning demonstrated on the trials.

THE HAZARDS OF SYNTHETIC PLASTICS

ACKNOWLEDGMENT

JOHN V. GRIMALDI, Director, Industrial Division, Association of Casualty and Surety Companies, New York, N. Y., is the author of this paper. Contributed by the Safety Committee of The American Society of Mechanical Engineers, the article was published in the December 1950 issue of "Mechanical Engineering." Mr. Grimaldi discusses the fire and toxic hazards of synthetic plastics, and concludes that plastics do not deserve the concern that has been felt from the standpoint of safety.

Estimates indicate that the increasing use of synthetic plastics has not even approached its maximum limits. Such large industries as automobile manufacturing offer a great potential for the employment of plastic products. Even today, a casual inspection of such articles as household appliances points out the current wide use of plastic products for decorative purposes and as a substitute for metals and other materials. The possibilities of plastics may even be beyond the limits of imagination.

FIRE HAZARDS

While "plastics" as a word and as a subject is certainly not new, its growing prominence in the industrial realm recently has focused attention on the fire hazards associated with the manufacture, use, and storage of plastic materials. Perhaps much of the present concern is the result of earlier experiences with pyroxylin, one of the first plastics. The nitrocellulose in pyroxylin burns violently, but most modern plastics do not have rapid-burning characteristics. Many have the quality of being relatively difficult to ignite (except when suspended in air as fine dust). However, because the general term "plastics" is applied to all synthetic and natural organic materials whose principal component is a resinous or cellulose binder and which are capable of being molded or cast, many people think of the fire hazard without regard to the type of plastic involved.

Even though the fire hazard of synthetic plastics may not be considered extreme, and some people may have been concerned unnecessarily, it is important to encourage such respect for hazards. Such attention means the important hazards will be uncovered and given the needed consideration, for accidents, it must be remembered, in the final analysis are always caused by thoughtlessness or unconcern on the part of someone. An understanding, however, of some of the more pronounced fire dangers associated with the manufacture of

plastics and the fabrication of plastics products may assist in the directing of safety efforts where they are needed.

The hazards that would be related to plastics manufacturing run the range from the general plant hazards, to the hazards identifiable with the particular materials, such as flammable solvents and dusts, used in the processes. The explosion and fire hazards are greatest in the manufacturing of the resins and in preparing the molding compounds for fabrication purposes. In the coating and laminating processes the use of volatile materials create the principal fire dangers.

In the manufacture of synthetic resins the major equipment used is reaction kettles or autoclaves, involving the heating and refluxing of the reaction mixtures until the required resin formation is achieved. Because the reactions, in general, evolve high heat, control periods are utilized to retard the exothermic character of the reactions. (Inasmuch as the companies manufacturing resins must be staffed with specialists well acquainted with the problems connected with their processes, it would be a presumption to outline those problems here).

The fabrication of the plastic products presents other hazardous possibilities. Many manufacturers' fabricating plastics may not be so well fortified, as are the resin manufacturers, with special personnel. Therefore, a review of the hazards in this phase of the business may be of value.

OTHER HAZARDS OF MANUFACTURE

Dust and faulty operation at high temperatures and pressures offer the greatest hazards in plastics fabrication. The dust hazards are found in the methods of using and handling molding powders; the tumbling of molded pieces in order to clean and polish them; the machining of molded parts; the cleaning of molds and dies with high-pressure air (also degreasing with flammable solvents during cleaning presents a fire hazard at this time); machine buffing of the molded parts to remove the excess overflow between the mold parting. Hazards are also found in the recovery and control of solvents employed in spraying, dipping, coating and laminating operations. The recovery of solvents often concentrates the impurities present, tending to produce lower boiling mixtures and reduced flush points, and ignition temperatures, than existed for the initial solvent. A properly designed recovery system adds to the safety of the operation, for it assures the collection of the volatiles. If they were to be permitted to dissipate, they might cause health and fire hazards. Some of the faith in depending on the physical characteristics of the solvents, as an indication of their behavior, is further shaken when it is realized that although the flash points, boiling points, and ignition temperatures of pure solvents are readily available, the impurities in the secondary or technical grades of solvents used in practice will alter these characteristics. Therefore, it is necessary to obtain this information from the supplier of each solvent or determine it in the laboratory.

CHANGE IN CHARACTERISTICS

Much of the apparent concern over the flammability of plastic materials is not justified, but is the result of unfamiliarity with the chemistry of plastics manufacturing. It is assumed by some that the chemical properties of the finished plastic product are approximately the same as those of the ma-

terials from which it was made. For example, when the toxic irritant formaldehyde is reacted with the corrosive liquid phenol the result is Bakelite, a solid infusible plastic, with new and different physical and chemical properties. Bakelite always will demonstrate its individual physical and chemical character—not the characteristics of the compounds used in its formulation—until it is acted upon to transform it to another compound. Then the characteristics will be those of the new compound. The phenol-formaldehyde resins are in wide use.

Another type is the vinyl resins which produce translucent materials, which may be colored, such as Vinylite and Geon and are used in sheeting, combs, umbrella handles, etc.

Polystyrene resins produce much the same products as the vinyl resins with the exception that they are not applicable for sheetings. These are known by such names as Cerex, Plexene and Styrons.

The ureaformaldehyde resins have wide popularity. They produce tough lightweight articles, such as the dishes known as Beetle and Plaskon ware.

The methyl methacrylate resins, produced as Lucite and Plexiglas, have wide application in the manufacture of sheeting for airplane cowlings, combs, handles, and the like.

Alkyd resins, such as Glyptal, are in coatings of many types ranging from varnishes to baking enamels.

A well-known plastic—cellulose acetate—is used for making photographic safety film, molded plastics, transparent sheeting, and it is often woven into fabrics. It is frequently known as Tenite and Lumarith.

There are many other resins. Perhaps, the best known of all is Nylon, a diacid-diamide, which is used for brush bristles, thread for hosiery and fabrics, and molded plastics.

Thus it is seen there is a great variety of synthetic resins, yet it must be kept in mind this list is far from complete.

FLAMMABILITY AND BURNING RATE

In general the synthetic plastics are difficult to ignite in comparison with wood. An exception is the highly flammable pyroxylin — more commonly known as guncotton. Whether a material will burn and at what rate and temperature is a function of its physical form and chemical composition. The physical form may be of greater importance than the composition. For example, a fine powder will burn more readily than a loosely formed mass, which in turn is less difficult to ignite than a solid. The dust from even a slow-burning plastic will explode when confined, under the proper conditions.

The relative flammability of plastics has been determined by the burning rate in inches per minute for an established gauge thickness. For example, cellulose nitrate was found to burn at 10-25 ipm, cellulose acetate at 2.0-4.0 ipm, polyethylene 1.1-1.4 ipm, and methyl methacrylate 0.5-1.0 ipm. It is interesting to observe that cellulose acetate has the second most rapid burning rate, even though its ignitibility is low enough for it to be used in the manufacture of safety film. However, in various experiments it has been shown that it is more difficult to ignite than pine wood, leather, or cellophane. Once ignited, the burning rate of cellulose acetate will be dependent upon whether a high-boiling plasticizer has been used. In general, the higher the boiling temperature of the plasticizer the more rapid the burning rate.

The selection of fillers has a great influence on the flammability of a plastic product. Organic fillers, such as cotton, paper, or wood are combustible

themselves, while inorganic fillers like mica and asbestos will not burn. All synthetic plastics, with the exception of the silicones, which are largely composed of silica, will burn if the temperature is high enough. Therefore, the flammability of a plastic largely composed of a resin and filler will be greater when the filler is organic than when inorganic filler is used.

An experiment was performed to demonstrate the effect of fillers. A paper-laminated phenolic was found at the time to ignite at the same temperature as cellulose acetate, 1100 F. A molded phenolic plastic with a wood-flour filler required a higher temperature to ignite. An asbestos-filled molded phenolic needed the highest temperature of all, 1500 F. before it would burn.

KNOWLEDGE OF PLASTICS COMBUSTION PROCESSES NECESSARY

Fire problems cannot be limited to the understanding and safeguarding of flammables, for when these materials do burn, it is necessary for the fire fighters to have a knowledge of the toxic products of combustion. The composition of the plastic determines the decomposition products of burning.

The burning process takes place in three steps:

1. A destructive distillation of the material, producing gases whose nature depends on the composition of the plastic.

2. Uniting of oxygen with free carbon to form carbon monoxide. At this time dense smoke is usually formed, presenting the additional smoke hazards.

3. When sufficient oxygen (more air) is present it combines with the flammable gases, produced in step 1, as well as the carbon monoxide from step 2. When there is enough air available to combine with all the combustible materials the carbon monoxide burns to form the relatively harmless carbon dioxide. Ordinarily, the products of complete combustion are less harmful than those of incomplete burning. The investigation of the possible generation of hazardous gases from overheated plastics is very incomplete.

However, knowledge of the composition of a plastic will lead to reasonably accurate approximations of its decomposition products.

CONCENTRATION OF GASES FROM BURNING PLASTICS

For example, cellulose acetate and certain vinyl plastics when incompletely burned produce acetic acid—an unpleasant irritating vapor when breathed. In general, nitrogen-containing plastics, such as the urea, melamine, and aniline formaldehydes produce hydrogen cyanide and ammonia when incompletely burned. An indication of the relative toxicity of these decomposition products may be given by the recommended maximum allowable concentrations for each.[1] These limits are based on a daily exposure of 8 hr. For hydrogen cyanide, the permissible safe limit is 10 ppm of air. For ammonia it is 100 ppm, for acetic acid, 10 ppm, and for carbon monoxide it is 100 ppm.

The phenol-formaldehyde plastics, when overheated, will produce some phenol and formaldehyde. The maximum allowable concentration for formaldehyde is 5 ppm. Although liquid phenol

[1] "Threshold Limit Values," *Arch Industrial Hygiene and Occupational Medicine*, vol. 2, no. 1, July, 1950, p. 98.

(carbolic acid) is a poison, no allowable concentration for its vapor has been recommended.

The chloride-containing plastics, such as vinyl chloride and vinylidene chloride, when partially decomposed by overheating, will give off hydrochloric acid whose vapors are very caustic and irritating. The maximum allowable concentration is 5 ppm.

The plastics partially composed of glycerine, such as certain of the alkyd resins, may, when heated, decompose to give the highly toxic product, acrolein. This product has a maximum allowable concentration of 0.5 ppm.

SUMMARY

The extreme concern over the fire hazards of synthetic plastics probably has arisen out of the experiences with pyroxylin in the early days of the plastics industry. It is probably safe to say that the greatest hazards exist in the manufacture of the resins, in the fabrication of plastic products, and in the grinding of scrap plastic. The burning of most of the plastics themselves should not cause any more concern than the burning of wood, woolen fabrics, or fats and oils. Some plastics such as vinyl chloride, do not support combustion but must be kept lighted by a separate source of heat.

The toxic products of combustion, while they must be considered, are for the most part of no greater danger than carbon monoxide, and this compound must be considered in the case of any fire. Concerning the other toxic products, the more common materials just mentioned will produce poisonous compounds when burned which are similar to those produced by the various types of plastics. Wood while burning will produce formaldehyde and acetic acid in fractions of a percent. Wool will give off hydrogen cyanide, as will silk, leather, and cheese also. Butter and fat will give off acrolein under conditions of incomplete combustion.

In summation, therefore, it can be said that plastics probably are not deserving of any more concern from the standpoint of safety than are many other compounds. But lest anyone be lulled into a complete sense of security, it should be remembered that "preparedness" is still the only safeguard against the unexpected.

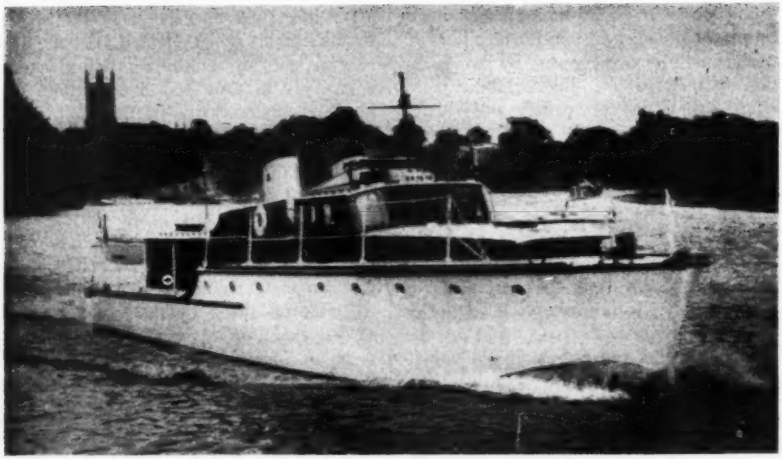


FIG. 1.—The launch *Torquil*, powered by two Rover gas-turbine engines

THE ROVER GAS TURBINE

ACKNOWLEDGMENT

This article was published in "The Shipbuilder and Marine Engine-Builder," November 1950. It describes the Rover gas-turbine engine installation in a 60-foot launch.

Among the various firms who have interested themselves in the development of the gas turbine is the Rover Company, Ltd., of Coventry, who are, of course, among the leading manufacturers of motorcars in this country. Earlier this year, at Silverstone, Towcester, the company successfully demonstrated an experimental motorcar in which the power unit was a gas turbine, and they have now carried the development a stage further with the demonstration, during October, of a 60-ft. launch (a former R.A.F. sea-rescue craft), propelled by two Rover gas-turbine engines.

The appearance of the launch—named the *Torquil*—may be observed in the photograph reproduced in Fig. 1, while the arrangement of the craft is shown by the drawings in Fig. 2.

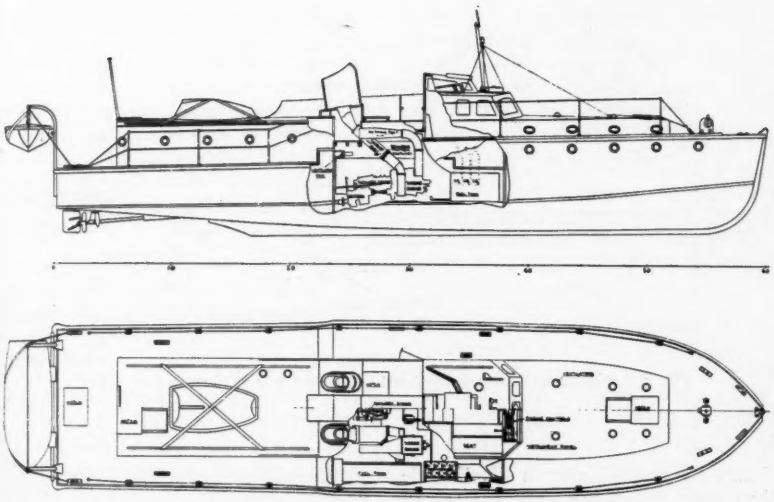


FIG. 2.—General arrangement of the 60-ft. launch *Torquil*

Originally, the propelling installation consisted of three Perkins Diesel engines, each developing 100 B.H.P. and driving a separate propeller. Two Rover gas turbines have been substituted for the wing Diesel engines; while the center unit has been replaced by a Dorman four-cylinder, 25-hp. Diesel engine, which is employed mainly for cruising, maneuvering, etc. This unit drives its propeller through an oil-operated 2:1 reduction gear.

The gas-turbine units installed in the *Torquil* are part of an order for a small number of these engines, entrusted to the Rover Company by the Admiralty —a circumstance which indicates that a stage has been reached at which the application of the Rover gas-turbine is becoming a practical proposition, at least for special purposes.

It must be emphasized, however, and the company themselves stress the point, that the problem of high fuel consumption remains to be solved before the gas-turbine engine can be considered for commercial service. The key to the solution of this question, states the Rover Company, is the design of a satisfactory and efficient heat exchanger. This is the one remaining problem, and the company's small, skilled team of engineers engaged on the gas-turbine project are continuing their work in this direction, especially with a view to the evolution of a compact unit, with dimensions much smaller than those of existing heat exchangers.

In consequence of the absence of heat-exchanging equipment in the installation in the *Torquil,* the fuel consumption is, of course, high—of the order of 1¼ lb per B.H.P. per hour at full power—the fuel employed in the launch being Diesel oil. Each turbine develops 100-120 hp. in continuous service, but it is hoped to increase the useful output to 180-200 hp.

The arrangement of the essential components of the Rover gas turbine is

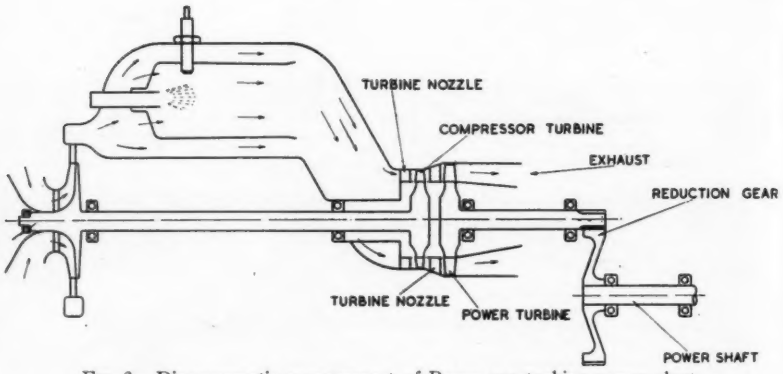


FIG. 3.—Diagrammatic arrangement of Rover gas-turbine power plant

shown diagrammatically in Fig.3, while the appearance of one of the sets can be seen in Fig. 4.

On admission to the plant, air from the atmosphere passes first through a single-stage centrifugal compressor, having a single-sided impeller, which rotates at a (maximum) speed of 40,000 rpm. Leaving the compressor, the air is conveyed to two combustion chambers, similar to those employed in aircraft jet engines, and here the air is heated by the burning of the fuel oil.

The hot gases pass from the combustion chamber to a turbine, which drives the compressor. The rotor of this compressor turbine is a forging (in Nimonic 90). In addition to providing the power for the compressor, it also drives all the auxiliaries.

Mounted behind the compressor is the independent output turbine, which is similar to the compressor turbine, in which the blades are somewhat larger than those in the compressor turbine, in order to provide increased area for the flow of the gases, the specific volume of which is, of course, greater at this stage of the circuit. The output turbine rotates at 30,000 rpm.

FIG. 4.—Rover gas-turbine power unit

The exhaust from the output turbine passes to the atmosphere via a diffuser, one function of which is to reduce the gas velocity.

The power from the turbine output shaft is transmitted to the corresponding propeller shaft in two stages, each incorporating reduction gearing. A single-reduction helical gear (7:1 reduction ratio), with oil-jet lubrication, effects the first stage; while the final stage is accomplished by a Wilson oil-operated reverse-reduction gearbox (3:1 reduction ratio), giving a propeller-shaft speed of about 1400/1500 rpm.

As mentioned in the foregoing, the auxiliaries, including the fuel-oil pump, lubricating-oil pump and electric generator, are driven from the compressor turbine. The fuel pump delivers oil to the two burners, which are regulated by a spill-type throttle control. The lubricating-oil pump is of the gear type, and supplies lubricant to all bearings and gears.

The starting equipment operates on the compressor turbine; a normal car-starter is employed, the step-up gear having a 3:1 ratio.

The adoption of a separate useful-output turbine endows the plant with exceptional flexibility. Control is effected by varying the fuel rate. The quantity of fuel burnt determines the speed of the compressor turbine and therefore the power output, independently of the speed of the power turbine.

The Rover gas turbine has been designed to give, eventually, an output of 200 hp., but, at present, the continuous rating is restricted to 100 hp., with a maximum of 150 hp. (full power). The specific fuel consumption at 100 hp. is about 1.6 lb per bhp. per hour, and 1.25 lb per bhp. per hour at full power. It must be remembered, of course, that these figures represent the performance of the set without a heat exchanger; the addition of a heat exchanger will greatly improve these figures, and it is anticipated that a full-load fuel consumption of approximately 0.8 lb per bhp. per hour will later be realized.

The space requirements and weight of the set are of interest. Each engine weighs approximately 4 cwt. complete and occupies a floor area about 4 ft., 0 in. by 2 ft., 6 in., while the height of the unit is 2 ft., 6 in.

During the recent demonstration of the *Torquil*, we were struck by the absence of vibration and noise. The craft responded promptly to the operation of the controls, which are located at the steering position. Starting was impressively smart, and the smooth maneuverability of the craft was abundantly demonstrated.

It should be mentioned, in conclusion, that the development of the marine version of the Rover gas turbine does not imply that the company has suspended or slowed down their work on the motor car engine. On the contrary, aided by the information and experience gained with the more powerful marine version, the company is continuing the development of the motor car gas-turbine engine.

THE SUPERCHARGING OF INTERNAL COMBUSTION ENGINES

ACKNOWLEDGMENT

This article is part of the 37th Thomas Hawksley lecture, delivered by SIR HARRY R. RICARDO at the Institution of Mechanical Engineers, London, on 17 November 1950. It was published in the December 1 and December 8 issues of "Engineering." The lecture dealt with the supercharging of both gasoline and Diesel engines, but this reprint confines itself almost entirely to Diesels.

Other things being equal, the power output of any internal-combustion engine is a function of the weight of oxygen it can assume in unit time; the nitrogen in the atmosphere is merely a passenger, though a very important passenger, in that its proportion controls the temperature of the combustion process. Sufficient fuel must, of course, be provided to combine with the whole, or at least as large a proportion of the oxygen as possible, but this, though a headache to the economist, presents no trouble at all to the engineer, for there is never the slightest difficulty in shoving into the cylinder all the fuel we require. The essential problem is how to stuff into the cylinder as much oxygen as possible and what to do with it when we have got it there.

Nature has provided us with a limitless supply of air containing a fixed proportion of oxygen, and that at a density which, at sea level, varies but little throughout the world. So long as we are content to accept the atmosphere she offers we may have as much as we like, but if we demand any change in the density or proportions, we must be prepared to pay the bill in terms of additional ironmongery, higher intake temperatures, and an expenditure of energy which may, or may not, be worth the price.

Until comparatively recently the digestion of the internal-combustion engine was such that it could barely cope with the heat released, or the pressures attained, by combustion with the quantity of oxygen inhaled from the normal atmosphere, but progressive improvement in mechanical design, in metallurgy, and, above all, in improved heat dissipation, has enabled us, at all events in the smaller sizes of engine, to cope with considerably more oxygen than can normally be aspirated.

There are a variety of ways in which we can supercharge an internal-combustion engine; for example, we can raise the pressure of the normal atmosphere by initial compression in some form of blower, driven either mechanically or by an exhaust turbine, or, to a more limited extent, by the use of ramming pipes or, in the case of two-stroke en-

gines, by exhaust pulsation. Yet again, we can increase the density by lowering the normal atmospheric intake-temperature by the evaporation of the fuel or of some liquid of low boiling-point and high latent-heat—in other words, by refrigeration; or again, merely by admitting extra oxygen at atmospheric pressure, either neat or in the form of an oxygen carrier; or, of course, by any combination of these methods. Of those I have mentioned, supercharging by means of ramming pipes, exhaust pulsation, or by refrigeration alone, will provide only a comparatively small increase in the oxygen content of the cylinder, while the use of additional oxygen is limited to certain specialized applications to which I will refer later. For most practical purposes we must employ some form of blower.

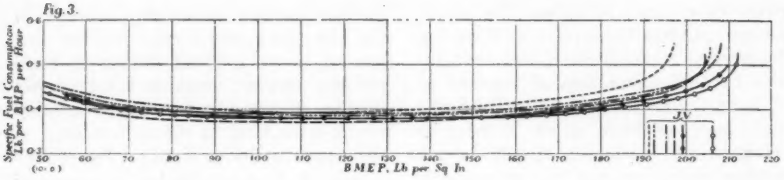
It is unfortunate that we cannot compress air without also raising its temperature, and this is the very last thing we want, for any increase in the initial temperature of the air involves a much larger increase in the high-temperature portion of the cycle and therefore both higher direct heat losses and loss due to change of specific heat and dissociation. Thus, as we raise the intake temperature, not only do we tend to lower the thermal efficiency, but we add very greatly to the distress of the pistons, exhaust valves, and other parts of the engine exposed to heat flow.

If we are going to supercharge to any considerable extent, not only do we need a highly efficient form of blower, but also some form of intercooling, and more especially does this apply in the case of a very high-compression engine such as the Diesel. We can, of course, intercool, either by means of a heat exchanger or by the evaporation in the air itself of some volatile liquid with a high latent-heat, and the choice will depend on the circumstances involved.

The reactions to supercharging of the compression-ignition and the spark-ignition engines are widely different. In the first place, the former has no fuel present in the cylinder during its compression stroke; hence it is completely immune from detonation or pre-ignition which set a limit to the performance of the spark-ignition engine. Again, by reason of its much higher compression ratio, the compression-ignition engine is still more sensitive to air intake temperature, for the temperature at the end of compression and before combustion starts is raised by compression to nearly three times the initial intake temperature; thus, if the air-intake temperature be raised by 100 deg. C. by compression in the blower, the final compression temperature will be increased by nearly 300 deg. C., and that before any heat is released by the fuel; the whole cycle-temperature will then be raised by a like amount, to the severe detriment both of thermal efficiency and of mechanical endurance. The higher, then, the ratio of compression in the engine cylinder, the more sensitive does the engine become to the temperature of the intake air, and the more urgent the need for some effective means of intercooling.

Let us consider the case of the Diesel engine, and more especially the light, high-speed Diesel engine. Here the case for supercharging appears to me to be an attractive one, for the compression-ignition engine responds to supercharging far more favorably than does the spark-ignition engine. In the first place, the awful bogies of detonation and pre-ignition are entirely absent. In the second, the higher the density of the intake air, the shorter the delay period, and therefore the smoother and the more controllable the combustion; further, the higher the intake pressure, the less sensitive does the engine become to either the cetane number or the volatility of the fuel; hence the wider the range of fuels it can digest. For example, Fig. 4 shows, superimposed, a number of indi-

Fig. 3.

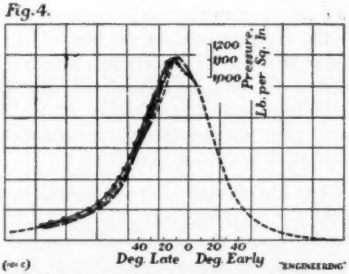


cator diagrams taken from a small supercharged Diesel engine running on a wide range of fuels ranging from a light gas-oil to boiler fuel oil of Admiralty specification. Fig. 3 shows the corresponding fuel consumption curves, the air on these tests being supplied by an independently driven blower. Without supercharging, the engine would not run satisfactorily on the heavier samples of fuel. Thanks to the shorter delay period, the optimum ratio of maximum to compression pressure falls as the intake pressure is increased.

In either the petrol or Diesel engine, the mechanical efficiency is, in practice, a function of the ratio of maximum pressure to mean effective pressure; the greater this ratio, the lower the mechanical efficiency.

In the petrol engine, doubling the intake density involves doubling the whole pressure scale throughout the cycle; in fact, rather more than doubling, because the clearance volume also is supercharged—but the ratio of maximum to mean pressure remains unchanged. In the Diesel engine, doubling the intake density considerably more than doubles the mean effective pressure but increases the maximum pressure by only about 40 to 50 percent, and this is all the more important since the ratio of maximum to mean pressure is higher, and the mechanical efficiency lower, in the Diesel engine, so that it has more

Fig. 4.



R.p.m., 1,250; booster, 20 in. of mercury; air-inlet temperature, 30 deg. C.; diameter of loading spring, 4 mm.; opening pressure, 100 atm.; diameter of plunger, 10 mm.; jacket inlet temperature, 70 deg. C.; oil inlet temperature, 60 deg. C.

Maximum pressure limited to 1,100 *lb. per sq. in. at* 150 *brake m.e.p.*

Fuel.	Injection, deg. Before Dead Centre.	Brake m.e.p.
Venezuelan Admiralty fuel oil	15	151·0
Venezuelan "B" grade Diesel fuel	14	151·0
Balik Papan Diesel fuel	14	155·5
Iranian marine Diesel fuel	15	150·0
Light industrial "A" grade Diesel fuel	14	152·0
Pool gas oil	14½	150·4

Load range curves, 1,250 r.p.m.; boost, 20 in. of mercury; air-inlet temperature, 30 deg. C.; diameter of spring, 4 mm.; opening pressure, 100 atm.; diameter of plunger, 10 mm.; jacket inlet temperature, 70 deg. C.; oil inlet temperature, 60 deg. C.

Maximum pressure limited to 1,100 *lb. per sq. in. at* 150 *brake m.e.p.*

Fuel	Injection, deg. Before Dead Centre	Barometer, in. of Mercury
Venezuelan Admiralty fuel oil	15	30·00
Venezuelan "B" grade Diesel fuel	14	30·80
Balik Papan Diesel fuel	14	29·81
Iranian marine Diesel fuel	15	30·19
Light industrial "A" grade Diesel fuel	14	30·46
Pool gas oil	14½	30·56

J.V.—Just visible exhaust limit.

to gain. Fig. 5 shows the results of a series of tests under supercharged conditions in which with a fixed quantity of fuel per cycle, the time of start of injection was varied. It will be noted that, under these conditions, very little is gained in power or efficiency by going beyond the constant-pressure diagram.

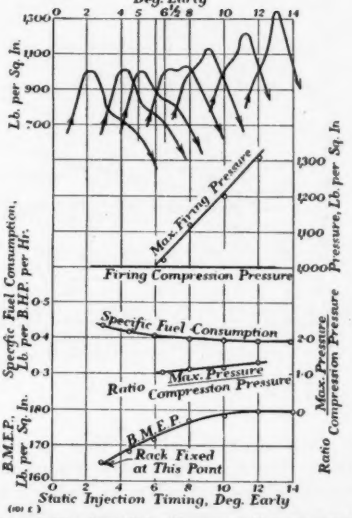
In both tyes of engine, doubling the intake pressure increases the heat flow by about 60 percent; thus the relative heat losses are reduced, but, though it is perhaps not generally realized, the Diesel is more vulnerable to heat loss and so has the more to gain. In the petrol engine, supercharging at low revolution speed leads to rough running and is early limited by detonation; in the Diesel, supercharging shows to best advantage at the lowest end of the speed range, where heat losses bulk large, also all Diesel knock is eliminated and the engine runs remarkably smoothly.

Both engines score heavily by intercooling, but the Diesel engine the more so, on account of its much higher ratio of compression. On the other hand, while the petrol engine can use its fuel as a refrigerant, the Diesel engine lacks this advantage and must depend wholly on a heat exchanger, though, in some cases, perhaps water injection might usefully be employed.

In the four-stroke Diesel engine, by virtue both of the longer expansion-ratio and the lower air utilization, the exhaust is much cooler and almost at a temperature which can be utilized in a turbine, so that an exhaust-driven turbo-supercharger can be used when the conditions are suitable, as in marine or industrial use. In the four-stroke petrol engine, the temperature of the exhaust is far too high, and a large amount of heat must be dissipated, with consequent loss of efficiency, before it can be used in a turbine.

Comparative tests on both petrol and Diesel engines of similar capacity have

Fig. 5



R.p.m., 1,250; boost, 20 in. of mercury at 60 deg. C. air-inlet temperature at 170 to 180 brake m.e.p.; standard throat, 0·088 diameter squared; opening pressure, 100 atmospheres; diameter of plunger, 10 mm.; standard cam rate, 4·9 cub. mm per crank deg. per litre; oil inlet temperature, 60 deg. C.; water inlet temperature, 70 deg. C.; pool gas oil, sp. gr. 0·848 at 15 deg. C.

shown that in both cases the relative heat flow to the cylinder walls and pistons diminishes with increase of density at the same rate as with increase of speed, that is to say, if the power output be doubled by doubling the speed at atmospheric density, or by doubling the density at the same speed, the heat flow in either case will be increased by about 60 percent, provided that the entering-air temperature is the same; but if, when supercharging, the induction-air temperature is allowed to rise, the heat flow will rise rapidly and more so in the Diesel than in the petrol engine. Fig. 6 shows the variation in gross heat-flow to the cooling-water with different air-intake temperatures.

In a high-speed high-compression engine of normal design little, if anything, is to be gained by cylinder scavenging, since the inlet and exhaust valves are

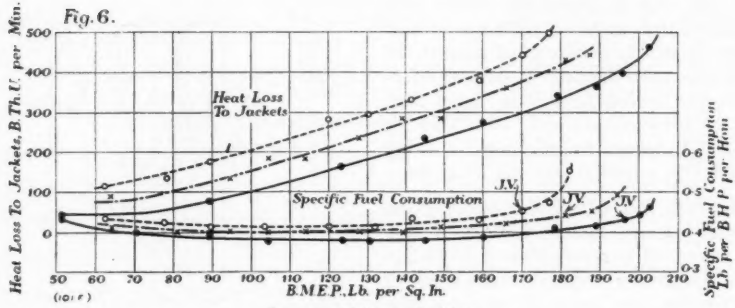


Fig. 6.
Heat Loss To Jackets, B.Th.U. per Min.
Heat Loss To Jackets
Specific Fuel Consumption
J.V.
Specific Fuel Consumption Lb. per B.H.P. per Hour
B.M.E.P. Lb. per Sq. In.
(10 i r)

Venezuelan "B" grade Diesel fuel.

Air-intake temperature, 90, 60, and 30 deg. C.; r.p.m., 500; jacket inlet temperature, 70 deg. C., oil inlet temperature, 60 deg. C.; diameter of spring, 4 mm.; opening pressure, 100 atm.; diameter of plunger, 10 mm.; injection rate, 3·2 cub. mm. per crank deg. per litre; static injection timing, 15 deg. C.

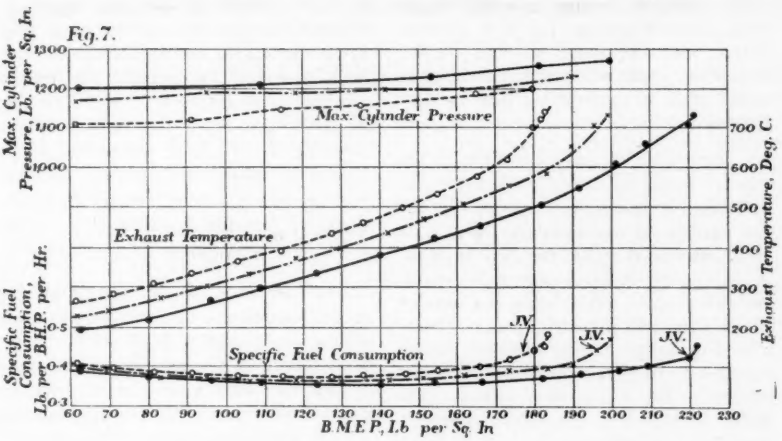
– – – – 90 deg. C. — · — · — 60 deg. C. ——— 30 deg. C. J.V.—Just visible exhaust limit.

in such close proximity that overlap timing results merely in short-circuiting. When account is taken of the loss of air (on which work has been done in the blower) and the necessary distortion of the combustion space in order to accommodate the valve overlap, the net result is generally negative. We have not been able to observe any measurable reduction in piston temperature even with very wide overlaps, involving a considerable loss of air. It would seem that it is only when an exhaust turbo-driven supercharger is employed that scavenging by valve overlap can be justified, and then rather as an expedient to reduce the exhaust temperature to a figure acceptable to the turbine. Even so, the practice of short-circuiting some air to exhaust outside the cylinder and under thermostatic or governor control so that it occurs only when the exhaust temperature exceeds a safe limit is, in my opinion, much to be preferred.

In the Diesel engine, the volume of the clearance is very small, usually only between 6 and 8 percent, and even at full load, contains nearly 30 percent of unconsumed oxygen, so that even if efficiency of scavenging were 100 percent, the gain in power would be very small; while as to internal cooling, we simply cannot afford to use expensive compressed air for this purpose. We can lower the exhaust temperature far more effectively by cooling the admission air, and that at no cost in energy and an appreciable gain in thermal efficiency; thus Fig. 7 illustrates the effect of varying the intake-air temperature on both the exhaust temperature and thermal efficiency.

By far the bulk of all high-speed Diesel engines today are used for the propulsion of heavy road-vehicles. In this service what is required above all else, is high torque at low engine revolutions, in order to reduce gear changing, to give good acceleration, and the ability to "hang on to" a high gear on hills. Ultimate power at maximum engine speed is seldom used and is of minor interest; what we really need, but cannot get with the petrol engine, is very high torque at low engine speeds. The supercharged Diesel should be ideal for this, for it behaves so excellently when heavily supercharged at low revolution speeds. If, by supercharging, we could obtain double the normal full load torque at the lower end of the speed range,

Fig. 7.



then it would appear that an engine of only 5-liters cylinder capacity would give about the same road performance as an unsupercharged engine of 8 liters. Unfortunately, no form of blower exists today which will provide the characteristics we want, i.e., the delivery of a small volume of air against a high pressure when running slowly and of a larger volume at a lower pressure when running fast. Clearly none of the conventional forms of blower will achieve this; we can dismiss at once the centrifugal or axial-flow blower as totally unsuitable; we can, I think, dismiss also the Roots' type for, having no internal compression, its efficiency is necessarily low when delivering against pressures of the order of 10 lb. to 15 lb. per square inch, and, in any case, its leakage path is so great that it will not deliver at all against a high pressure at low speed; and the latter objection applies also to such blowers as the Lysholm, or those of the sliding-vane type, for although they provide internal compression they also have very long leakage paths. Inevitably it seems we must fall back upon some form of piston blower which alone can provide internal compression, combined with very small leakage losses, and which could be designed to give a drooping volumetric-efficiency curve; the urgent problem before us today is, I think, the design and development of an elegant form of piston blower for such a service.

Many supercharged Diesel engines have been and are running on the roads today, using either Roots' or sliding-vane type blowers, but their performance is a little disappointing in that the high supercharge is not available at the time when it is most needed.

Our general experience, after a good many years of experiment on supercharged Diesel engines of the type and size in question, is that an engine of reasonably robust but perfectly orthodox design, and using the usual modern bearing materials, etc., can quite safely stand up to a supercharge which will double its torque at low speeds, even without any intercooling, but that if the same supercharge be applied and made full use of at its top speed, thus doubling the maximum power, the heat flow will be too great and it then becomes necessary to take such measures as oil-cooling

the pistons, using special materials, or even sodium-cooling for the exhaust valves, etc., but much depends on the degree of intercooling that can be provided and, in a vehicle, this is very limited.

I have dealt at some length with the case of the Diesel engine for heavy road-vehicles, for this service employs by far the bulk of all Diesel engines, large or small, produced today, not only in numbers, but also in total aggregate power, the other main fields being for marine propulsion and industrial work generally. For large marine engines, whose rotational speed is limited by propeller efficiency, the two-stroke cycle is generally preferred. A two-stroke engine is normally supercharged to the extent that its air supply is delivered at a pressure in excess of the atmosphere, but since its cylinder forms a free passageway and is not a cul-de-sac, as in the four-stroke engine, air can pass through it freely, and the degree of boost is dependent upon the resistance to flow offered by the exhaust ports. Although some supercharge can be attained by appropriate port timing, or by making use of exhaust pulsation to drive back some of the air spilt out of the exhaust ports, the scope in this direction is limited and the only means of applying a really substantial supercharge is by the imposition of back pressure. This, however, places a heavy burden on the scavenging blower, for the two-cycle engine requires about 50 percent more air than does the four-cycle, and since the process of filling the cylinder is carried out while the piston is hovering around bottom center, no part of the blower work is returned, by pneumatic transmission, as in the four-stroke engine. Supercharging, therefore, by raising the exhaust back pressure, is hardly tolerable unless an exhaust turbine be used, in which case the whole, and even more than the whole, of the additional blower work can be recovered. Fitted with an exhaust turbine, any degree of supercharge can be applied to a two-cycle engine, for the higher the exhaust back pressure, the greater the return, and that with interest, from the turbine until, in the limit, the turbine is developing the whole of the useful power, that of the piston engine being absorbed entirely by the blower. The piston engine then performs the same function as the boiler in a steam plant.

The demands of marine propulsion are, of course, the very opposite to those of the road, in that high torque is required only at the top end of the speed range. For such a service the exhaust turbo-blower seems the obvious solution for the four-cycle engine, for it provides the supercharge just when it is most needed, with the minimum expenditure of useful energy; much the same, of course, applies to the industrial engine which runs normally at a constant speed. Exhaust turbo-blowers are, however, expensive luxuries and are efficient only in relatively large sizes. I do not think their use would be justified for engines of less than, say, 150 hp. For smaller industrial or marine engines, some form of mechanical blower, such as the Roots', Lysholm, or sliding vane, is preferable, but none such, in small sizes, efficient at pressures over about half an atmosphere, and if we are going to supercharge a small engine at all, we want to do it thoroughly. We have recently built up an experimental engine of about 40 brake horsepower per cylinder, using a piston supercharger sandwiched between two working cylinders and delivering alternately a double supercharge to each of them. There is, of course, nothing novel in such a scheme, but the advantages of supercharging, particularly perhaps in the better combustion of heavy and low cetane fuels, appeared to be great enough to justify it, now that we know how to cope with high rates of heat flow.

So far, only a few preliminary tests have been carried out on this experimental engine, but already it has shown itself capable of developing a net brake mean pressure of 200 lb. per square inch with a perfectly clean exhaust. Thus, this converted three-cylinder engine—for we have merely substituted a pumping cylinder in place of the center working cylinder—is already giving very nearly the same power output as a four-cylinder of the same cylinder dimensions. The general running so far is remarkably smooth and quiet at all loads; its weakness lies in the fact that it provides no intercooling.

Finally, to sum up: the conclusions I have come to, so far, are that it is not worth while supercharging the spark-ignition engine except in the case of aircraft or racing cars, but that in the case of the four-cycle Diesel, it pays, hands down, to do so, and would pay most handsomely of all in the road-vehicle field, if and when a suitable blower can be developed for this service.

HARD FACING OF STEAM VALVE SEATS AND DISKS

ACKNOWLEDGMENT

OSCAR E. SWENSON, welding engineer, U. S. Naval Engineering Experiment Station, Annapolis, Md., is the author of this article which was published in the December 1950 edition of "The Welding Journal." The article deals with the general welding procedure, the fundamental differences in heating effects of low, medium and high velocity tips and evaluation devices used at the Experiment Station. It was presented at the Thirty-first Annual Meeting, American Welding Society, Chicago, Illinois, during the week of October 22, 1950.

INTRODUCTION

Nature renews herself by growth; man-made machines wear out. Since the beginning of welding, one of its many uses has been the reclamation of worn parts; and for this purpose, special hard-facing materials and techniques have gradually been developed.

Hard facing by braze welding provides the engineer with a convenient method for obtaining a hard wear-resistant surface on metal parts. Special alloys in the form of welding rods and portable oxyacetylene welding equipment make the process readily applicable whether in the shop, aboard ship or on the beachhead. The useful application of hard-facing materials depends upon the selection of appropriate welding rods and equipment, the skill of the welder, and the enginering knowledge that permits good judgment in utilizing the materials.

Hard facing forms a protective layer which resists abrasion, corrosion, impact, seizure, heat or any combination of these wear factors. The primary function of hard facing is to prolong the life and increase the operating efficiency of the part involved. New, as well as worn parts, may obtain these benefits by the application of a thin layer of hard alloy to the position where it is most needed. In fact, hard facing finds its greatest over-all economy when applied to new parts.

PURPOSE OF TRIMMING VALVES

The welding operation known as hard facing has proved to be a practical and economical procedure for trimming valves.

The Navy requires that valve seats and disks for high-temperature, high-pressure steam service be furnished with hard facings. Hard-faced valves reduce power losses to a minimum and are free from scoring and undercutting even under the severe conditions of drip or throttle service. Repeated heating and cooling does not warp or distort the properly applied wear-resistant overlays. In addition, the low coefficient of friction of the hard-facing alloys is especially valuable in valves where the disk travels in a rotating or wiping motion over the face of the seat.

GENERAL WELDING TECHNIQUE

The deposition of hard-facing alloys requires a braze-welding technique rather than a fusion welding technique. The surface to be overlaid must be clean and prepared by grinding or machining to remove all oxide and scale. The following is presented as a general guide for applying hard-facing alloys.

Welding Torch and Tip Sizes—Any approved type of oxyacetylene welding torch with low velocity tips may be used for the deposition of hard-facing alloys. It is important that the high velocity tips be avoided as the force of the flame jet may cause localized overheating of the base metal with resultant dilution of the hard-facing deposit and erratic hardness results. A, B and C in Fig. 1 illustrate the differences between low, medium, and high velocity tips. Note the square shoulders in the low velocity tip, the slanting shoulders in the medium velocity tip and the straight-lined swaged taper for the high velocity tip. The inner cone of the low velocity tip has a pronounced bulbous shape which spreads the heat onto the base metal. As illustrated, the inner cone lengthens and the bulb becomes smaller as the velocity of the gas increases. Tip sizes should be: 0.0465 bore (No. 56 drill) for material not over 3/16 in. thick; 0.0670 bore (No. 51 drill) for material 1/4 to 7/16 in. thick; 0.0760 bore (No. 48 drill) for material 1/2 in. thick and over.

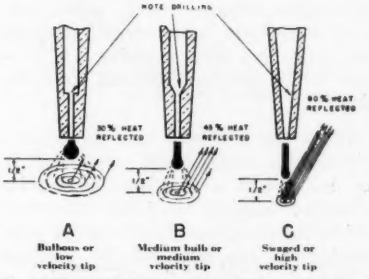


Fig. 1 Illustrating heating effects of low, medium and high velocity tips

As velocity of gas increases due to the drilling inside of tip, the inner cone lengthens and the flame bulb becomes smaller

(Modification of a copyrighted illustration, courtesy of the Walworth Company)

Flame Adjustment—The flame for hard-facing alloys must contain an excess of acetylene. One exception to this rule is the application of Alloy "C" on objects of small mass requiring only local preheat and a neutral flame. The desired flame adjustment for each alloy is shown in Table 1 as a ratio between the length of acetylene feather and the length of the inner cone, both being measured from the end of the torch tip. Illustrations of a neutral flame, 2:1 and 4:1 ratio flames are shown in Figs. 2, 3 and 4, respectively. Acetylene and oxygen 2-stage pressure regulators are preferred, and the settings should be 4-5 psi. for a No. 3 tip, 5-7 for a No. 5 tip and 6-8 for a No. 6 tip.

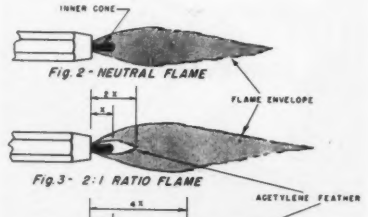


Table 1

NON-FERROUS HARD-FACING ALLOYS			
HARD-FACING ALLOY	APPROXIMATE COMPOSITION	FLAME ADJUSTMENT RATIO*	DEPOSITION CONDITIONS
A	Co 55 % Cr 33 % W 6 %	3 - 1 TO 5 - 1	1- HIGHLY REDUCING FLAME IS ESSENTIAL IN MOST APPLICATIONS. 2- DEPOSITION IS MOST SATISFACTORY WHEN MADE WITH A MINIMUM OF REMELTING.
B	Cr 13 % Ni 76 % B 3 %	2 : 1	1- SLIGHTLY REDUCING FLAME IS PREFERRED. 2- DEPOSIT CAN BE REMELTED TO IMPROVE CONTOUR.
C	Cr 17 % Ni 70 % B 4 %	1 : 1 TO 3 : 1	1- MODERATELY REDUCING FLAME IS PREFERRED IN MOST APPLICATIONS. FOR OVERLAYING SMALL OBJECTS A NEUTRAL FLAME IS RECOMMENDED. 2- DEPOSIT CAN BE REMELTED TO IMPROVE CONTOUR.
D	Cr 28 % Co 21 % Ni 13 % Mo 6 %	3 : 1	1- MODERATELY REDUCING FLAME IS PREFERRED. 2- DEPOSIT CAN BE REMELTED TO IMPROVE CONTOUR.

*LENGTH OF ACETYLENE FEATHER TO LENGTH OF INNER CONE

Acetylene gas requires 2½ times its own volume of oxygen for complete combustion. Approximately equal volumes of the two gases are fed through the torch, and the remaining 1½ volumes of oxygen are obtained from the air.

When the acetylene gas is burning without the oxygen gas turned on, it has a brilliant white flame caused by white-hot carbon particles, some of which escape unburnt and can be seen floating in the air. As the oxygen is turned on and adjusted to give a neutral flame the size of the white flare decreases until it does not extend beyond the small white cone. When the acetylene supply is increased the white flare again appears, indicating that free carbon particles are present. When a flame with this acetylene feather is used for hard facing, the carbon particles tend to carburize the surface of the base metal and also to reduce any oxides of metal. The excess acetylene flame is thus both carburizing and reducing.

Terminology in the field for the degree of acetylene flame varies widely. Consideration is suggested to designating a descriptive mathematical ratio of length of acetylene feather to length of inner cone for a qualitative measure of the amount of acetylene flame.

Size of Welding Rod—The 3/16-in. diameter welding rod is handled most conveniently, but when the width of the surface to be overlaid is less than ¼ in. or when the base metal thickness is less than 3/16 in., a ⅛-in. diameter rod should be used. If the smaller rod is not available, it may be produced by drawing out the larger rod as the soft flame from a tip with a 0.0465-in. bore, adjusted as for hard surfacing, is directed on the end of the rod to bring it to a plastic condition. Figure 5 illustrates the drawing out of a ⅜-in. rod onto a heavy chill table. The skilled operator does not require a mold, but the beginner may find a grooved plate of carbon, graphite, iron or steel to be helpful. A length of angle iron could be used as a mold. The drawn out rod can be redrawn to progressively small diameters, if desired.

Use of Flux—Flux is not required, under normal conditions, for deposition of a dense overlay. The general rule is to avoid the use of flux.

Support of Thin Sections—When depositing on seats of thin sections it is often necessary, in addition to using a small welding tip, to back up the underside of the seat with wet asbestos fibre cement or carbon paste to absorb the excess heat. This method permits the heating of the base metal to the temperature required to form a union with the deposited alloy, yet prevents the melting of the base metal which would cause dilution of the alloy. Melting of the base metal may be prevented by slightly rounding any sharp corners in preparation of the surface to be overlaid. An excessive melting of the base metal forms an alloy with the overlay to give a deposit of unpredictable behavior.

For hard facing such light work as the point of a high-pressure needle valve, an Aircraftsman's small torch can be better regulated than the standard size unit, even though the latter is used with a No. 0 or No. 1 tip. The hard-facing

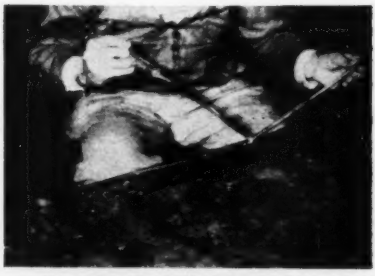


Fig. 5 Drawing out rod to smaller diameter

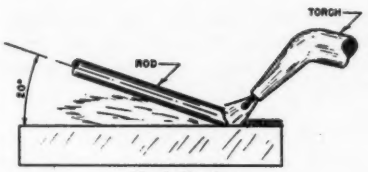


Fig. 6 Starting

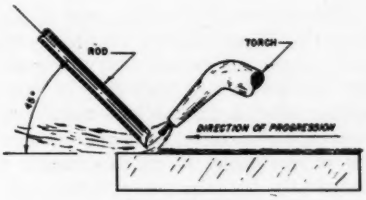


Fig. 7 Finishing

rod may be redrawn as often as is necessary to reduce its mass to match that of the light work.

Direction of Welding—The proper direction for progression of welding is obtained with the forehand method of deposition. The relative position of work, rod and flame for starting deposition is shown on Fig. 6, and the finishing position is shown on Figure 7. As most welders are right-handed, the following description for applying hard-facing alloys may be considered standard.

The torch is held in the welder's right hand, the welding rod in his left. During preheating, the flame is directed almost normal to the work surface at a distance gauged by the free length of the acetylene feather.

During deposition, the torch is tilted so that the flame is pointed in the direction of progression and held close enough to the work so that the inner cone of the flame is not more than ⅛ in. from the surface.

Pointing the flame to the left as the direction of welding progresses from right to left, permits the gas envelope to shield the metal as it melts from the rod and flows evenly on the work, while impurities are floated out.

The rod, carried in the welder's left hand, is held at about 20 to 45° above the horizontal (see Figs. 6 and 7), so that the welder's vision is not impaired and his hands are not exposed to the rising heat of the flame. The rate of melting off, the flowing on, the leveling and scavenging of the deposit are thus always in full view of the welder.

Preheating—It is advisable to preheat the entire surface of the work that is to be overlaid. The degree of preheating depends upon the mass of the work. Small objects are given only a local preheat while heavier pieces (5 lb. and over) must be preheated to not less than 650° F., preferably in a furnace. Preheating is mandatory to avoid localized dilution which results when employing high torch-fed heat, and to prevent the formation of porosity. A lower velocity rate of heat input from the oxyacetylene flame permits a larger portion of the base metal to absorb more of the total heat applied before fusion occurs. Careful preheating lowers thermal gradients and thus minimizes cracking tendencies. Contact pyrometers or temperature smear sticks may be used to determine when 650° F. has been reached. Care must be exercised not to apply the smear on the clean surface prepared to receive the hard-facing alloy.

For smaller objects, the welder need only apply a light over-all preheat and then hold the flame on the spot where deposition is to start until sweating appears to be constant and begins to spread ahead of the flame. During this period of localized heating, the welding rod should also be preheated by being kept at the outer edge of the flame envelope. When the sweat of the preheated surface does not disappear the instant the torch is lifted slightly, the base metal is ready for overlaying.

Deposition—The welding rod is put into the flame slightly ahead of the inner cone and melted onto the work. As soon as the first large drop of hard-facing alloy is on the base metal, the welding rod is withdrawn from the center of the flame. If the base metal is sufficiently hot, the alloy flattens out and flows ahead of the flame, spreading on the work exactly like solder. If freshly deposited Alloy "A" does not spread out, it has to be heated with the torch until it does. The other alloys in Table 1, however, may be deposited rough and then remelted readily to obtain a smooth bead contour. Avoid puddling and penetration of the base metal as this dilutes the deposit and lowers its resistance to abrasive wear.

The flame must be kept on the deposit until all impurities have been floated off; these appear as white flecks swimming on top of the deposit. The deposit must look bright and smooth before additional metal is added to it. Once the base metal is of the correct temperature for spreading the deposit, progress of the work is rapid. It consists of alternately dropping the metal from the rod onto the end of the existing deposit, withdrawing the rod to the outer edge of the flame, and playing the flame on the last drop until the deposit is free of impurities. The required thickness of the overlay shall be deposited in a single layer whenever it is possible to do so. When, upon completion of a deposition, porous spots and/or low areas are discovered, such parts shall be remelted with a low velocity flame and the conditions corrected before the deposit cools. When completing a circular deposit such as on disks, it is advisable to finish the deposition with a "shrinkage tail," i.e., the final deposit is carried up over the starting end of the bead and finished off at either side of the start to provide an extra "tail" of hard-facing metal. Upon remelting the deposition, the "shrinkage tail" provides material at the point where shrinkage requires additional metal.

Postheating and Cooling—It is considered good technique to bring the disk or seat to an even heat immediately after deposition is completed and then to place it in lime for slow cooling. One method is to back the torch off gradually from the work instead of removing the torch abruptly from the union between the first and last laid metal, so that possible cracking at the termination of the depositing is prevented. After completing the deposition, the flame is played on the disk or seat, passing around the work two or three times.

Precautions on Interchangeability—All of the alloys in Table 1 are interchangeable and satisfactory results may be obtained by observing the above instructions. A special precaution must be observed, however, when Alloy A is used to overlay Alloys B or C. As the melting point of Alloy A is higher than for either Alloy B or C, it is unavoidable to remelt a small volume of the latter metals when a repair is effected with Alloy A. To avoid development of porosity in the repair area, the deposition of Alloy A must be performed with a highly reducing flame adjustment with the ratio of the acetylene feather to the inner cone at 5:1. It is mandatory to remelt only the unavoidable minimum volume of the original overlay. Best results are obtained when the deposited Alloy A does not require remelting. Should remelting Alloy A be necessary, it may be done using care that the jet of the flame does not cause a depression in the heated overlay. The soft flame of the low velocity tip will aid in observing this precaution.

NONFERROUS HARD-FACING ALLOYS

The nonferrous hard-facing alloys have been found most suitable for trimming high-temperature steam valves. Some of these alloys are shown in Table 1, with their approximate composition, flame ratios, and deposition conditions for best results. Properties which make the nonferrous alloys desirable for overlaying steam valve seats and disks are (1) they maintain strength and hardness at elevated temperatures, (2) they resist abrasion and corrosion, (3) they have low coefficients of friction and (4) they have good welding characteristics.

TABLE 2

	Brinell hardness			
Overlay	*Room temperature*		*1100° F.*	
Thickness	*Range*	*Average*	*Range*	*Average*
⅛"	367-391	378	279-299	286
1/16"	361-396	381	261-325	284
Base Metal	380-383	382	221-255	240

DETERMINING SUITABILITY OF ALLOYS

To determine the suitability of hard-facing alloys for use in the Naval service, they are first given a screening test consisting of edge welds on ¾- × ¾- × 6-in. medium steel keystock and on 4½-in. diameter disks cut from ⅜-in. thick steels of carbon molybdenum, 25-20 stainless, and ⅜-in. thick Monel metal. The welds are made in one-pass approximately ⅛ in. thick and subsequently ground to a thickness of about 3/32 inch.

During deposition, which is accomplished with the forehand technique, the flow characteristics, ease of deposition and bead contours are observed. Remelting characteristics of the alloys are noted when it is necessary to remove surface defects or to improve smoothness of the deposit. The ground deposits are examined for porosity, checks or blemishes of any type. Uniformity of hardness is determined for the ground deposit on the keystock. A minimum hardness of Rockwell C-40 is expected for the as-deposited alloys.

The ground disk specimens are subjected to thermal shock by placing them in a furnace, the temperature of which is maintained at 1050° F. Specimens are held in the furnace for 30 min. and then cooled in air to room temperature. This cycle is repeated 25 times with an examination of the overlay after each cycle for cracks, employing the Oil-Powder Flaw Detection Method.

Hard-facing alloys found acceptable to the above screning tests are subjected to hot hardness and hot impact tests. Specimens for hot hardness are deposited in single layers on ¾- × 1½- × 1½- in. blocks of 4-6 Cr, ½ Mo steel. One specimen is tested at room temperature, and one at 1100° F. Typical Brinell hardness data, in Table 2, for overlays ground to ⅛ and 1/16 in. thickness includes hardness data on the base metal as affected by the heat of welding.

Simulated valve seat and disk assemblies, as shown under the 20-lb. hammer in Fig. 10, have overlays ground to 1/16

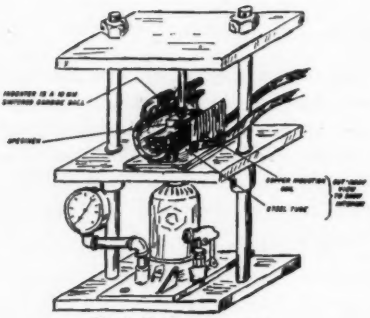


Fig. 8 Hot hardness tester

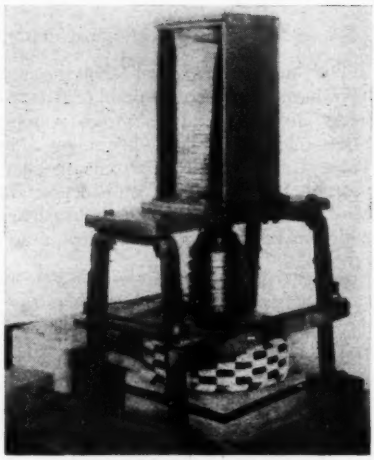


Fig. 9 Hot impact machine

or 3/32 in. thickness for hot impact testing. Evaluating methods are given under the following description of the testing devices.

Testing Devices—Testing devices designed at the Engineering Experiment Station for determining hot hardness, hot impact values and steam tightness are shown in detail in Figs. 8, 10 and 11, respectively. A photograph of the hot impact machine is shown in Fig. 9.

The hot hardness machine is operated at temperatures up to 1100° F. The standard 3000-kg. load is applied to obtain the impression with a sintered carbide 10 mm. ball. The diameter of the impression is read in the usual manner with the Brinell microscope and converted to the Brinell hardness number.

The hot impact testing machine may be operated at various temperatures. The detail information on the sketch is self-explanatory. It has been determined that a satisfactory valve seat and disk overlay will withstand 500,000 impacts of the 20 in.-lb. hammer at the rate of

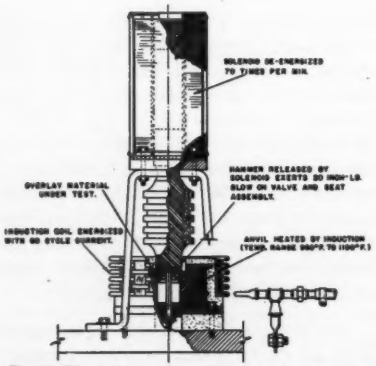


Fig. 10 Elevated temperature impact testing machine

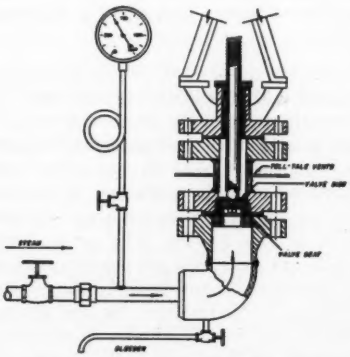


Fig. 11 Device for testing steam tightness

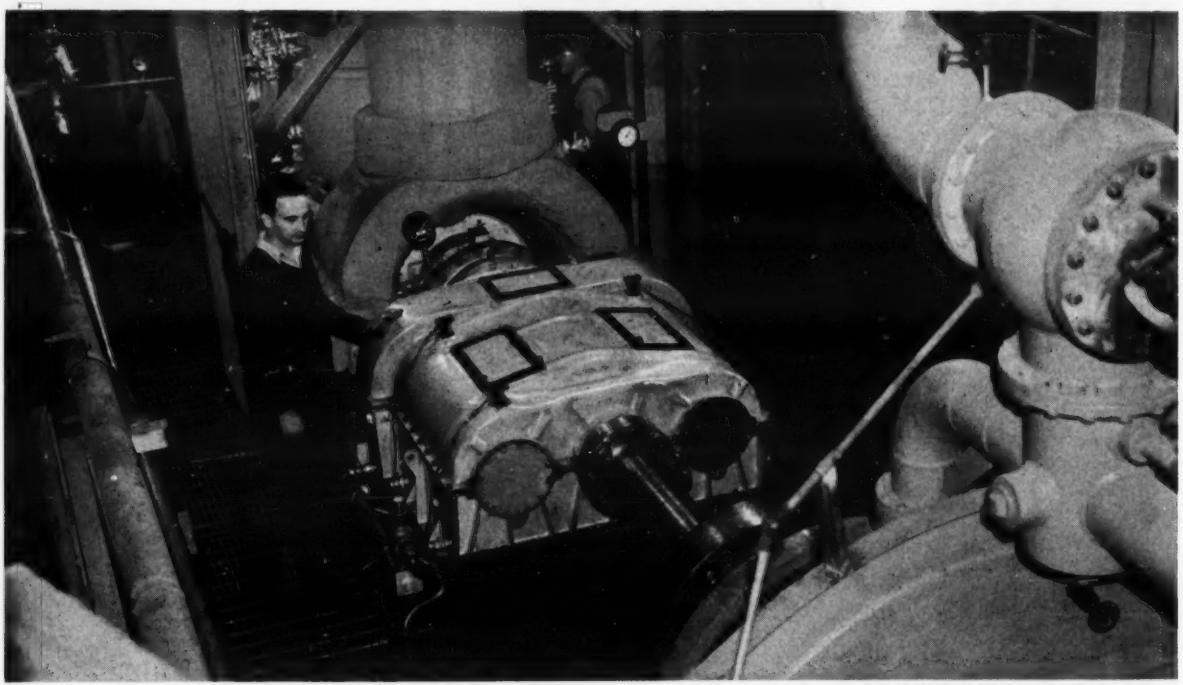
70 blows per minute without showing flaws when given the critical examination of the Oil-Powder Method.

The steam tightness tester is employed before and after subjecting the valve seat and disk assembly to hot impact. Any leakage of the saturated steam past the seat and disk would be seen at the telltale vents. This test aids in determining wear or defects in the overlay.

Actual service tests of hard-facing alloys can be performed at the Engineering Experiment Station not only in various steam lines, but also as exhaust valve overlays in various Diesel engines at the Station's Internal Combustion Engine Laboratory.

Acknowledgments

Grateful acknowledgment is made to Bela Ronay, Superintendent, and J. H. Siegel, Welding Branch Head, Welding and Electrical Laboratory, U. S. Naval Engineering Experiment Station, for their helpful suggestions and constructive reviews of this paper; to J. W. Hopkins, Jr., Draftsman, for preparation of the sketches; and to other staff members of the Welding and Electrical Laboratory—particularly to F. X. Henderson, Welding Engineer, whose practical knowledge of hard facing was especially helpful.



Official United States Naval Photograph

Experimental Reduction Gear, with plastic gear case cover, on test at U. S. Naval Boiler and Turbine Laboratory.

BOOK REVIEWS

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BY EDWIN F. CHURCH, JR.

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REVIEWED BY COMMANDER IVAN MONK, USN
Member, A.S.N.E.

In his third edition the author has rewritten and added to the material contained in previous editions with the result that the third edition is approximately twice the size of the previous editions. Most of the drawings, photographs and descriptions represent modern practice. The text is well-arranged and is presented in a clear, interesting manner. In addition to a well-rounded treatment of the thermodynamics of the turbine and its elements the author has included chapters on elementary aerodynamics, materials and stresses, vibration, and governing. The unique requirements of marine turbines are covered in a chapter which deals with arrangements and special applications of turbine components.

Although this book was written as a text for undergraduate and graduate students, it is particularly valuable as a reference for practicing engineers who frequently find it desirable to review basic principles without having to read through masses of material purporting to elucidate those principles. For the benefit of those who wish to study specific phases of the subject in greater detail the author has prepared a comprehensive, up-to-date bibliography which includes the work of numerous A.S.N.E. members.

METHODS OF OPERATIONS RESEARCH

By

PHILIP M. MORSE AND GEORGE E. KIMBALL

Published jointly by:

THE TECHNOLOGY PRESS OF MIT AND JOHN WILEY & SONS, INC.

REVIEWED BY REAR ADMIRAL RALPH E. MCSHANE, U.S. NAVY

In the words of this book, "Operations research is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control." With that as a start the authors proceed to reveal some startling applications of mathematics to certain *operations* of World War II. The applicability of these methods is best revealed by repeating some of the problems described: "Aircraft Search for Submarines," "Convoys versus Submarines," "Tactics to Evade Torpedoes," "Aimed Fire—Small Targets."

The book primarily is a text book and much of the mathematical treatment will be beyond the capabilities of the "executives" for whose aid the research is designed. Despite that fact it would be profitable reading for most military officers, line and staff, for the problems which are used as examples of methods can readily be understood by the non-mathematical. It is sufficient to recognize the great utility of the methods as aids in the solution of operational problems. While the examples are almost entirely in the field of military strategy and tactics it is clear that the general methods are applicable to other forms of "operations."

The authors are explicit in avoiding any implication that the methods of operational research are the answer to all operational problems. It is made clear that such research is only one of the areas of information on which the executive must base his decisions. In the words of the authors, "The operations research worker must work out those aspects of the problem that are amenable to quantitative analysis and report his findings to the executive. The administrator must then combine these findings with the qualitative aspects to form a basis for the final decision. This decision must be made by the executive officer."

It is not unreasonable to expect that the methods described here will find wider application and be brought to bear on many problems outside the strictly military field. A general understanding of the principles of this form of research, its applicability, limitations and utility would be a profitable addition to most "executives'" store of knowledge.

"THE ENGINEERING METHOD"

By John Charles Lounsbury Fish

Publisher: Stanford University Press, Stanford, California; 1950

The material presented in this book was originally published as part of "The Engineering Profession" (by Hoover and Fish, Stanford University Press; 1941; 2nd Edition, 1950). The book presents the system of logic and reasoning that an engineer must use, and is intended to be of use to the engineering student or recent graduate, and to experienced supervisory engineers in furnishing guidance to their engineering assistants.

The book is written in a very clear and direct manner. It is divided into three sections. The first, "The Method of Engineering," begins with several pages on logic and engineering reason, then presents some preliminary definitions, and finally presents the various steps in the engineering method, using as examples some very excellent nontechnical problems.

The second section, "Application of the Engineering Method," discusses the actual process of applying the engineering method to practical problems. Four problems are solved, starting with that of determining the hypotenuse of a right triangle and ending with the selection of the source of water supply for the city of San Francisco.

The final section presents various examples of uncertainties that an engineer is of necessity confronted with, together with a description of typical methods of dealing with them.

This is an excellent book and one which is highly recommended for young engineers.

THE ANALYTICAL BALANCE, ITS CARE AND USE

By William Marshall Macnevin

Publisher: Handbook Publishers, Inc., Sandusky, Ohio; 1951

This book, termed a monograph by its author, was written in response to many requests received by the author for information about the balance. It describes the component parts of a balance, the methods of mounting, cleaning and assembling, and the testing and adjusting of a balance. It also contains a very clear discussion of how to use a balance, which will be of interest to technical workers who have had little or no training in the use of such equipment.

"GRAPHICAL METHODS FOR POWER ESTIMATION OF FISHING BOATS"

By Atsushi Takagi, Takao Inui, and Shoichi Nakamura

Publisher: Fisheries Agency, Kasumigaseki, Chiyoda-Ku, Tokyo, Japan

Fishing craft, compared with other ships, have a comparatively large beam and draft in proportion to their length, and hence the displacement-length ratio is considerably higher than is usually found in the design of ships. Moreover the speed-length ratio is high and Froude's number exceeds that of ordinary merchant ships. Accordingly the wave-making resistance forms the major part of the total resistance.

Because of the very high displacement-length ratios involved, Taylor's standard series charts cannot be applied. At the same time very little experimental data are available to provide comparable information for ships of this type.

This book reports on model experiments of tuna and bonita clippers and presents an extensive series of charts applicable to such fishing boats. The book is written in English.

CONTROLS SERVICE

Publication of a new weekly "Controls Service," indexing and digesting the welter of new price, production and distribution regulations, has just been inaugurated by the Journal of Commerce. This new service consists of Master Editions of all-inclusive "Controls Guide" at six-week intervals, and weekly "Bulletin Summaries" designed to keep each master edition constantly up-to-date. The newest Master Edition has just been issued, containing an Index showing the restrictions now in effect on 1,697 different products and services, and the digest of 82 control regulations and their amendments. A timetable outlining "What's Ahead in Controls" is also included on a range of 32 product groups. Subscriptions to this weekly Controls Service may be had at $25 per year from the New York Journal of Commerce, 63 Park Row, New York 15. Master Editions of the "Controls Guide" are $1 each.

CHANGES IN MEMBERSHIP

It is with great pleasure the announcement is made that the following new members have been admitted since the publication of the February, 1951, JOURNAL:

NAVAL

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THE FOLLOWING HAVE RESIGNED:

NAVAL

Lt. Commander R. B. Goodman, Jr., U.S.N.R.

CIVIL

John F. Nichols

ASSOCIATE

Commander J. E. Best, R.N.

Captain Frederick G. S. Bowring, R. N.

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $40.00 to $150.00 depending upon length, interest and professional value.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

Manuscripts should be mailed addressed to:

Secretary-Treasurer
American Society of Naval Engineers
605 F St., N. W.
Washington 4, D. C.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 10 reprint copies of his article free of charge. Additional copies may be purchased from the Society if the request is received 30 days prior to the publication date which is the 25th of the issue month. Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which insufficient material is already on hand.

SUBJECT MATTER AND AUTHORS

To assist the editor in programming future issues, the help of all members is solicited. To make it easy, the last page in this issue is readily detachable as you will find. This page has blanks for two entries.

(a) What subject would you, as a member, like to see covered by an article in the JOURNAL.

and

(b) Who do you consider best qualified to prepare such an article authoritatively, and what is his address (if you know).

Any of these forms which are filled in and mailed to the Society will be received with thanks and the editor will follow up to get the suggested articles prepared.

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold background.

It is available to all members at fifty cents (50c) each.

LIFE MEMBERSHIPS

Any member may now purchase a life membership under the following rules:

(a) Any dues paid for the year in which life membership is purchased will be credited to the cost of the life membership.

(b) Life memberships are non-transferable and terminate with the death of the member.

(c) No refund will be made on account of death or resignation of a life member.

(d) Life membership will vary in cost with the age of the member at his next birthday following application, as follows:

Over 55 years	$125.00
40 to 55 years	175.00
25 to 39 years	225.00
Under 25 years	250.00

(e) All life memberships paid in shall be protected by a transfer on the books of the Society of Series G, U. S. Government 2½ per cent bonds. Thus a life membership will be established. It will be credited with moneys paid in for life memberships and debited with the regular amount of annual dues for each life member each year.

LOCAL CHAPTERS

Local Chapters of the American Society of Naval Engineers may now be authorized by the Council. The following rules for recognition of Local Chapters have been adopted by the Council:

(a) Twenty or more regular members, Naval or Civilian, may apply for a Charter as a Local Chapter.

(b) Each application must be accompanied by a list of members and a copy of local By-laws. The latter must meet the following minimum requirements.

1. All financial dealings of the local Chapter must be independent of the Society and can in no way obligate the Society as a whole. The local chapter shall set up on a non-profit basis. All accounting shall be local.

2. Each active local Chapter shall receive from the Society a grant of $0.50 per year for each naval member, civil member or associate who resides in the local area and who associates himself with the local Chapter. This grant may be used by the local Chapter to defray any necessary expenses, including (a) Letterheads, (b) Notice cards, (c) Postage, (d) Minimum rental allowance, (e) Secretarial service (part time).

3. Any technical papers presented at local chapter meetings, shall be submitted to the Secretary-Treasurer of the Society for consideration for publication in the JOURNAL. Any paper accepted will be paid for at regular rates.

4. Each local chapter shall submit a quarterly report of its activities to the Secretary-Treasurer. These reports must reach Washington, D. C. prior to 15 January, 15 April, 15 July and 15 October. This report shall contain a list of active local members as of the first day of the quarter for the purpose of computing the amount of grant.

5. Associate members of the Society shall be eligible for membership in a Local Chapter, entitled to all the privileges of other members except voting and holding office.

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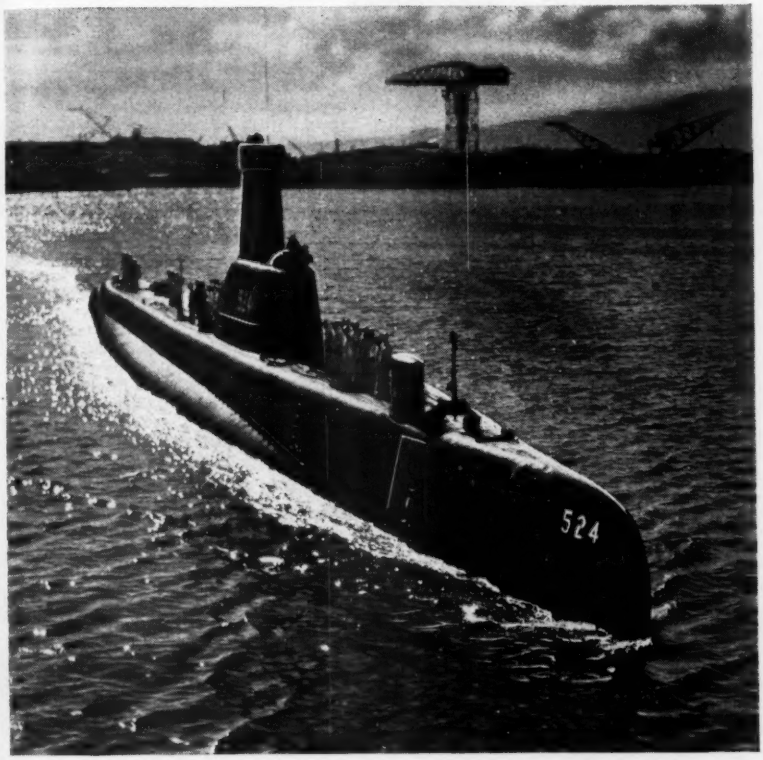

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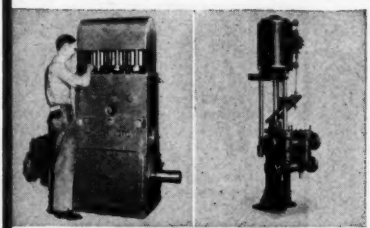

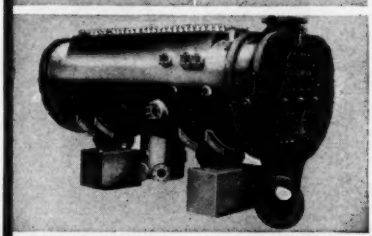

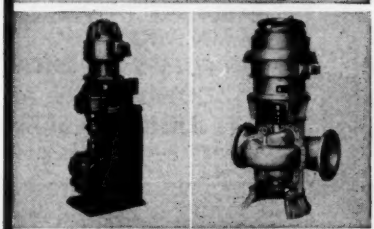

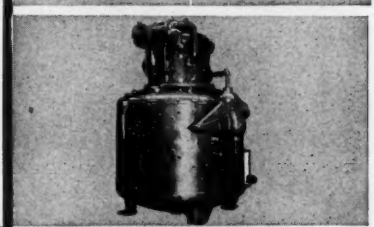

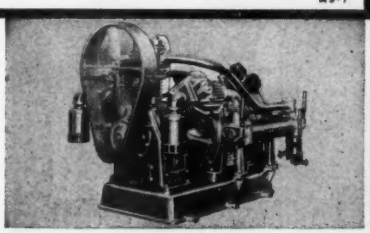

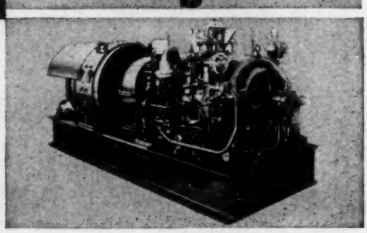

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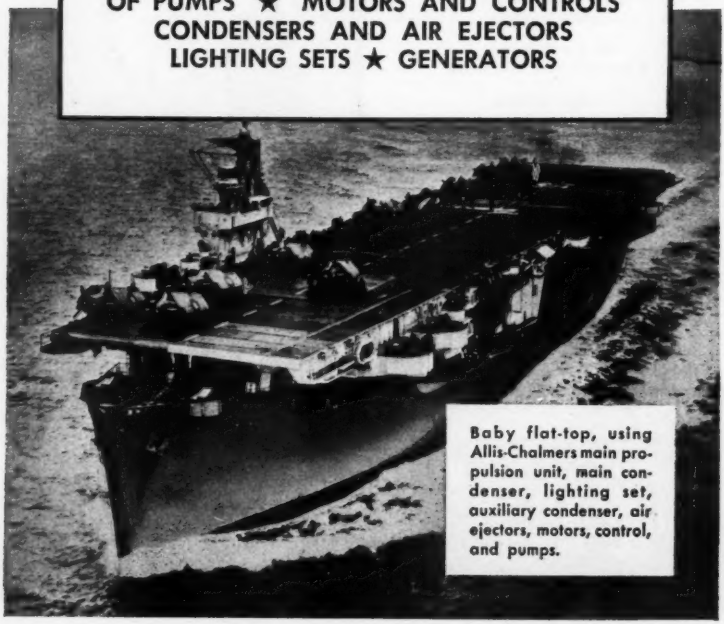

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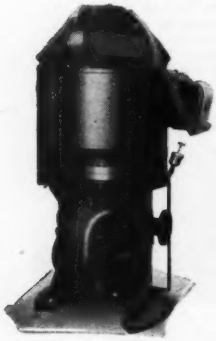

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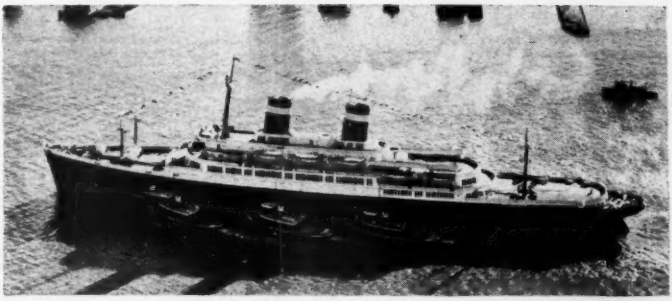

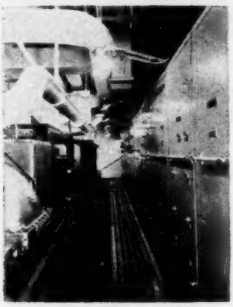

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Photograph courtesy of Cummins Engine Company, Inc., Columbus, Indiana

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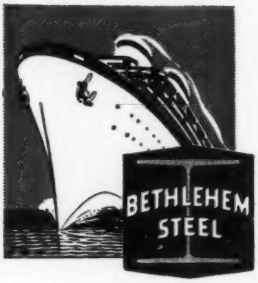

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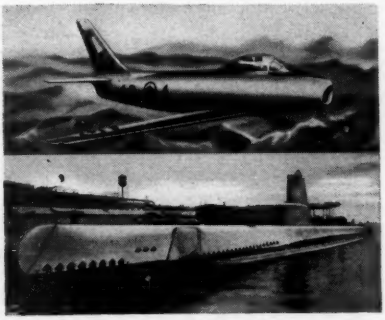

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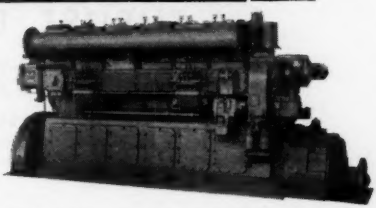

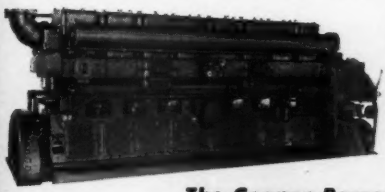

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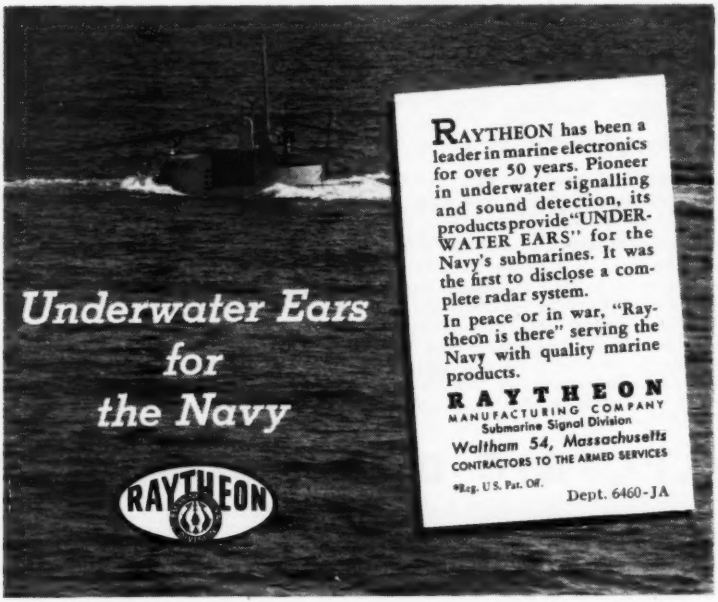
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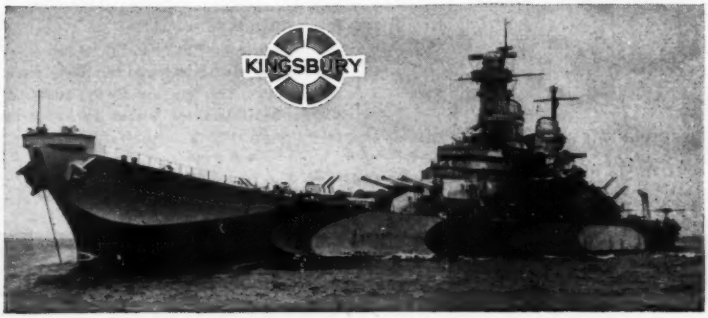

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